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DESIGN OF LARGE BRIDGES WITH SPECIAL REFERENCE TO THE QUEBEC BRIDGE.*

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IT is rather a difficult matter to draw a line between a large bridge and one of ordinary size. My definition of a large bridge would be a bridge which involves a considerable expenditure of money, or presents unusual difficulties of construction, or both. Bridges which by force of circumstances and local conditions span long distances may, therefore, be classed as large bridges. It has been my good fortune to be connected with the design and construction of several large bridges, and I shall deal, in the course of this paper, with the salient features of those structures, while at the same time trying to deduce a few general principles which should govern the design of large bridges. I shall also refer to structures designed by other engineers. It would, of course, be impossible in a single paper to cover the field in detail and in an exhaustive manner; I can only bring out some of the more important questions which should be considered by the designer of such structures. In what follows,

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the Quebec Bridge, with its single span of 1800 feet, 100 feet longer than the Firth of Forth Bridge,[1] will be referred to frequently. As that bridge is now under construction, and as the first attempt to build it resulted in a great disaster, the structure will be of particular interest.

Location.—The first question which the engineer has to deal with, when considering a bridge project, is the location. In the majority of cases this location has previously been fixed, either exactly or within a small range. Whenever this location is not fixed exactly, the engineer makes surveys of the various possible locations, from which surveys preliminary sketches are drawn and estimates prepared. One of the most important conditions to consider in this comparative study is the character of the foundations. Complete borings to determine the kind and quality of the material through which the foundations are to be built, and on which the finished work is to rest, are indispensable. In the case of a railroad bridge it is not always the location giving the cheapest bridge which gives the most economical results. As an instance, let us consider the Celilo Bridge across the Columbia River. A bridge at the Dalles, 12 miles below Celilo, would have been cheaper, but the bulk of the traffic over this bridge being east-bound, the location at Celilo was, on the whole, more economical, as saving about 24 miles in the distance to be traversed by such east-bound traffic. Another important feature in deciding on a location is the permanency of the river bed. A bridge should not be located where there is a reasonable possibility that the stream may change its course. If such a location is unavoidable, the shores should be protected and the river regulated for some distance above the bridge.

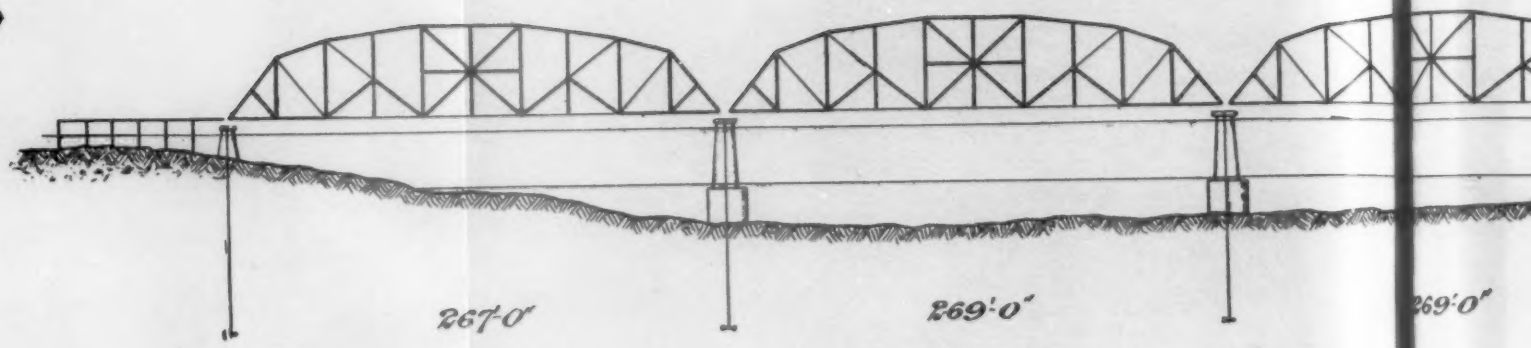
When the location has finally been fixed, more borings should be taken, several at each pier, to establish beyond any reasonable doubt the character of the materials. I am laying great stress on this point, because it is so frequently neglected. Such neglect often results in serious disappointment as to the ultimate cost of the bridge, in differences as to settlement with the contractors, and in delays.

Length of Spans.—While sometimes the length of spans is

[1] The span of the Forth Bridge is sometimes erroneously given as 1710 feet. This is the distance between centres of main end uprights, but the distance between centres of bearings at the bottom chord is 1700 feet.

SHAW'S ISLAND

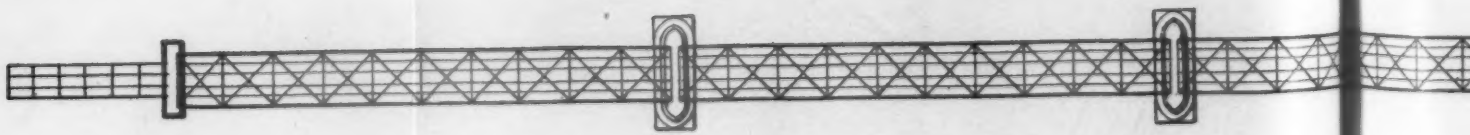
2286 ft. Pile trestle

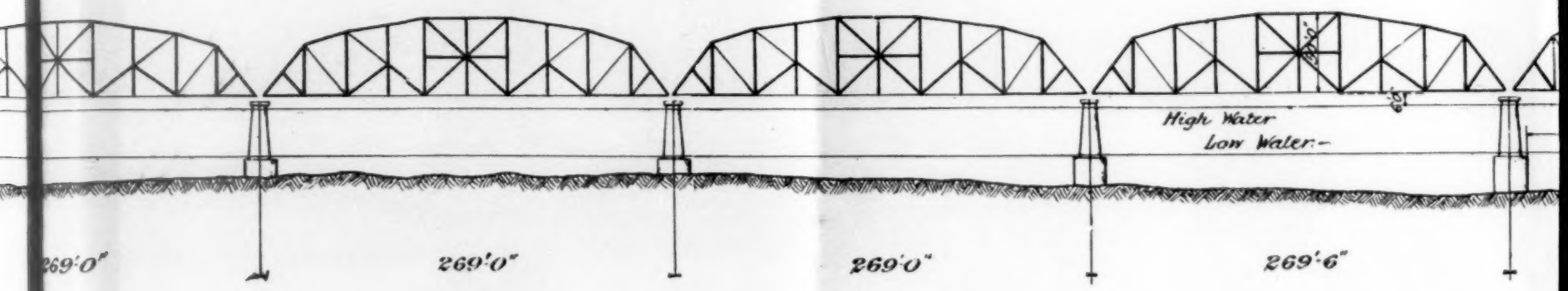


Pier X

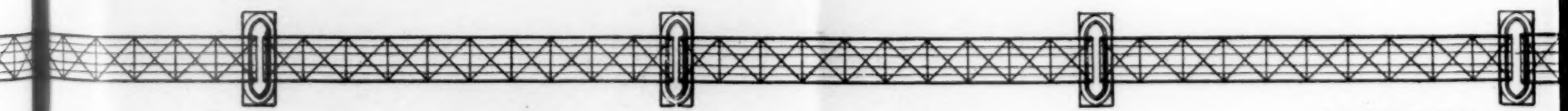
Pier IX

Pier VIII

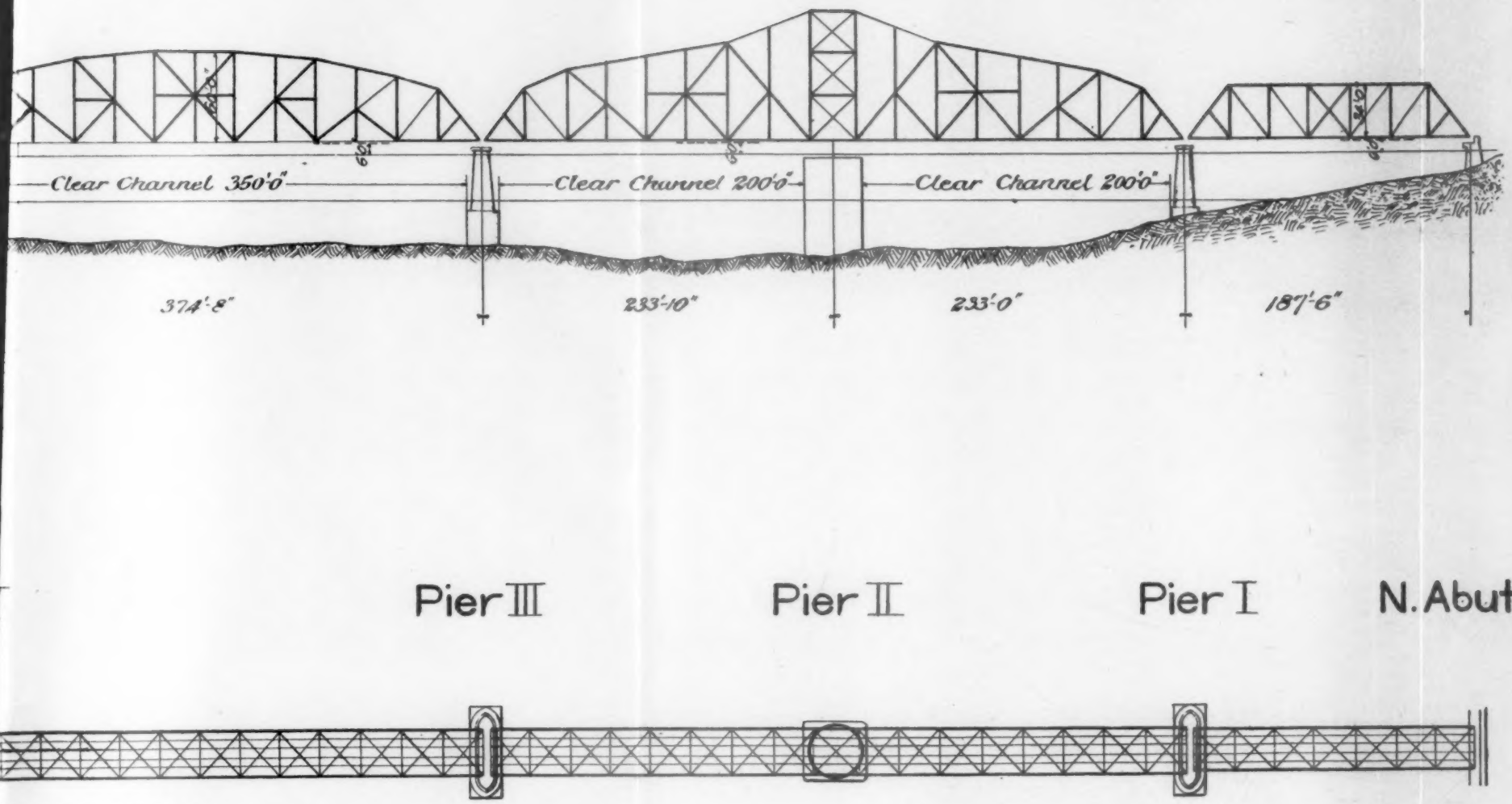




Pier VII Pier VI Pier V Pier



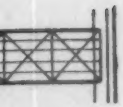
Columbia River Bridge at Vancouv

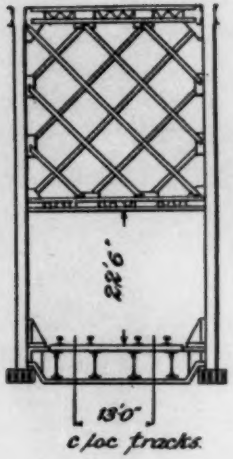


Washington, channel crossing.

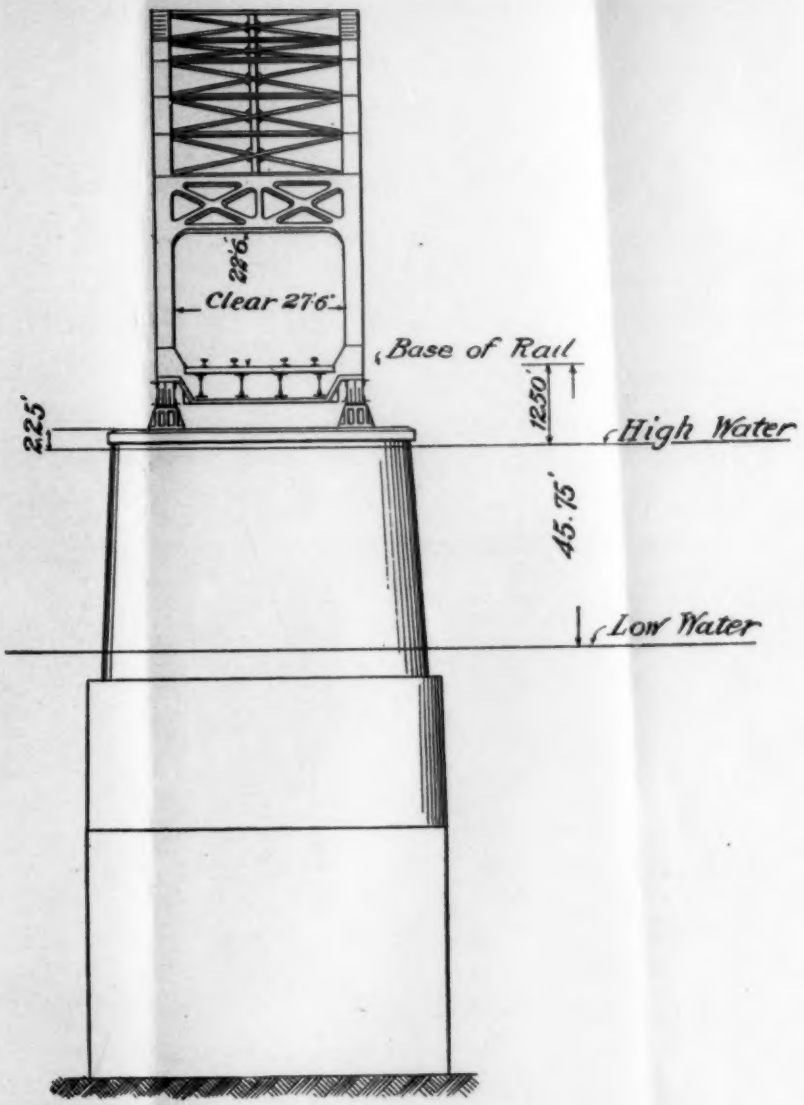
VANCOUVER

N. Abutment





Section at center
Span III-IV



Elevation Pier III

governed by the cost of the foundations and piers, more often such length of spans is fixed by requirements of navigation or other circumstances. The Government, in giving permission to build a bridge over navigable waters, generally imposes the clear opening of one or more spans, and passes on the design as a whole. It also imposes the minimum clear height above water. Sometimes the ruling of the Government results in an injustice to the railway corporations, as for instance in the case of the Memphis Bridge. The minimum clear height imposed for this bridge by the War Department was 75 feet above highest water known. A clear headroom of 65 feet would have been sufficient, and, if permitted, would only have involved the removal of useless ornaments on pilot-houses of three or four boats, and a provision for lowering the smokestacks on a few boats, similar to the provision existing in the Ohio River, where the required clear headroom above high water is only 53 feet. The additional ten feet not only increased the cost of the bridge considerably, but resulted in heavy grades in the approach in Memphis and a disturbance in street grades.[2]

Often draw spans or movable bridges are required over streams where there is no navigation, on the theory that some boat might wish to come through some day. But it must be said that in the majority of cases the rulings of the Government engineers are just and necessary for the proper protection of navigation. Where no limitation is placed by the Government as to length of all spans, as in the Columbia River Bridge at Vancouver, for instance, in which only the lengths of the draw span and of the adjacent or raft span were stipulated, the spans should be made of economical length, provided the piers do not reduce the cross-section of the river sufficiently to cause an undesirable increase in the current velocity. This economical length may be determined by trials, and will be attained approximately when the cost of the superstructure and of the substructure are nearly equal. This well-known principle has been applied in determining the length of the six 265-foot spans of the Columbia River Bridge (Plate I).

The charter for the Thebes Bridge provides that it "shall have at least one channel span, with a clear channel way at low

[2] See Geo. S. Morison: A Report to Geo. H. Nettleton on the Memphis Bridge, 1894.

water of not less than 650 feet, and all other spans over the waterway, at a bank-full stage, shall each have a clear channel way at low water of not less than 500 feet, and all such spans shall have a clear headroom of not less than 65 feet, etc." So here the length of spans as well as the clear headroom is definitely fixed by the Government requirements.

In the case of the Quebec Bridge, while the navigation interests fixed the clear height of the structure above high water at 150 feet, the length of span is entirely due to the physical

FIG. 1.

Original project for the Quebec Bridge in 1884–1885 by Messrs James Brownlee, A. Luders Light, and T. Claxton Fidler.

conditions of the crossing. The stream at this point is narrow and deep, the depth in the centre of the stream being about 190 feet. The current velocity at ebb-tide is very high—about nine miles per hour. Very heavy ice runs at times and tends to gorge. The bed rock, as shown by the borings, while accessible near the shore lines, dips rapidly towards the centre of the stream. All these conditions made it imperative to build a span of great length. The information as to bed rock which we now have would indicate that the original project could have been designed with a somewhat shorter span. Yet we should remember that this original project was undertaken by a private cor-

poration, and we should perhaps recognize the value to it of such advertisement as the building of the longest span in the world would obviously afford. The next longest span is that of the Firth of Forth Bridge, and is 1700 feet long. It is doubtful if a shorter span than 1700 feet would have been practicable at the location adopted for the Quebec Bridge. I consider it perfectly legitimate to build a more expensive structure than economy of the work itself would call for, if the more expensive structure will afford sufficient advertisement and publicity to compensate for the additional expenditure. Cases also often arise where a purely economical and utilitarian structure would be entirely out of harmony with the surroundings. We have a good illustration of this policy in the magnificent stations which the railway companies are constantly building.

A project to build a large bridge at Quebec, presumably in the same location as the present one, was seriously considered in 1884 and 1885. Messrs. James Brownlee, A. Luders Light, and T. Claxton Fidler designed a structure with a clear span of 1442 feet[3] (Fig. 1). The description of that project mentions rock foundations. The more complete information we now have, and which was obtained by a costly series of borings, shows that at the present location rock could not have been attained in both piers with any known method of foundation if the piers had been spaced only 1442 feet apart, even if the great depth of water could have been overcome.

It may be remembered that after the disaster of August 29, 1907, the Dominion Government took up the reconstruction of this bridge. A board of three engineers, including myself, was appointed to design and construct the bridge. After some study of the situation, the board decided that the new bridge should be made wider between trusses and designed to carry heavier loads than those originally contemplated; that, further, none of the old steel work could be used to advantage. It also decided to keep the same location. To discuss the reasons for these conclusions would take up too much space in this paper. The final outcome is a double-track span of 1800 feet, with a width of 88 feet between centres of trusses, designed to carry on each track a live load consisting of two E 60 engines[4] placed in any posi-

[3] *London Engineering*, vol. xxxix, 1885, p. 336.

[4] Theodore Cooper's specifications.

tion in a train weighing 5000 pounds per foot so as to produce greatest strains. The old piers were not large enough for the new design and could not, therefore, be used. The centre line of the bridge running north and south the two main piers on each side of the stream will be designated as north pier and south pier respectively. At first the board contemplated building an entirely new pier 57 feet south of the present north pier, and enlarging the foundation of the south pier by sinking additional caissons adjacent to the old caisson. The necessary span length would then have been 1758 feet, and it was on that length of span that tenders were asked. It developed later, from the experience of sinking the north caisson,

FIG. 2.

Aqueduct of Gard at Nimes, France.

that the method proposed for enlarging the south foundation would not be safe, even if it were practicable, and so an entirely new foundation and pier were decided on for the south shore. The new north pier could not be placed farther out in the river because of the sloping bed rock and great depth of water. The south pier could not be placed on the north, or river, side of the old south pier, because of the old wreckage, so it was placed 64 feet 8 inches south of the old pier, or as close as possible to it. Both new piers being placed 64 feet 8 inches south of the old piers, measured between centres, the new span remains 1800 feet long.

The piers are all of granite backed with concrete. There is an increasing tendency now to build everything of concrete. Certainly, concrete is a most convenient material and quite eco-

nomical. When it comes, however, to providing supports for a very important and expensive structure, cut stone masonry should be used in preference to concrete, except for backing. There are many varieties of excellent building stone on this continent. I have used granite, some varieties of oolitic limestone, also sandstone, which all show excellent lasting qualities in works constructed many years ago, while concrete presents some uncertainties and requires expert care to give good results. Concrete may in ages prove to be as lasting as stone masonry, but as yet we do not know. We know that well-constructed stone masonry will last for centuries. A notable example of this is the great Aqueduct of Gard, built by the Romans in the first century B.C. (Fig. 2).

Types of Superstructure.—Having fixed the span lengths of a bridge, the next thing to determine is the type of superstructure to be used. The various types usually applied to long spans may be classified as follows:

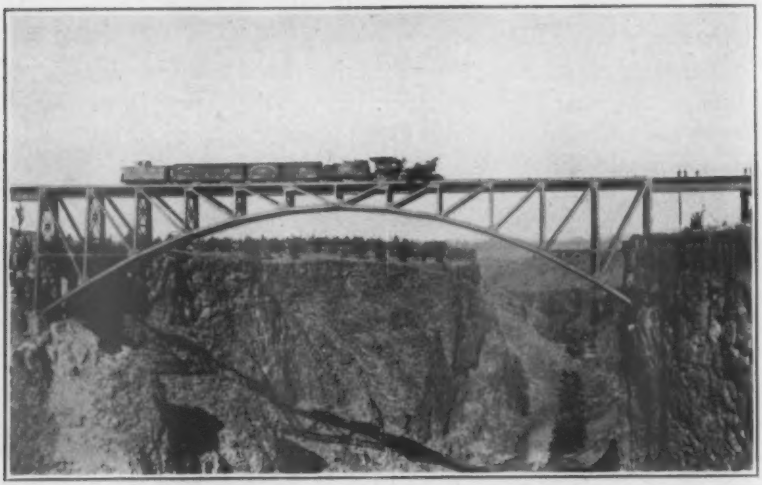
I. Arches (steel).
   a. Three-hinged.
   b. Two-hinged.
II. Simple spans.
III. Cantilever structures.
   a. With suspended span.
   b. Without suspended span.
IV. Suspension bridges.

I have purposely omitted masonry and concrete arches as structures not coming clearly within the scope of this paper. Steel arches have a rational application only where Nature has provided natural abutments, as at Niagara Falls, for instance, or where natural surroundings lend themselves to ornamental construction.

Crooked River Arch.—I have recently completed an arch bridge for the Oregon Trunk Railway in the Crooked River Canyon (Fig. 3). It is a two-hinged spandrel braced arch. Three-hinged arches are now seldom used for railway bridges, because they are less rigid than two-hinged arches. They still have a good application in roof trusses which are not subject to heavy and rapidly-moving loads. In several large arch spans the central connection offered considerable difficulties. The reason

is that the top chords at the centre of a purely two-hinged arch are calculated to have stresses in them, due to dead load and temperature, when the span is riveted up and ready to receive the rolling load. These stresses had to be introduced by powerful jacks, or other means, before the final joint could be riveted up. To avoid this difficulty, I have proceeded as follows in the Crooked River arch. It was assumed that the dead load and temperature stresses at 60° F. in the top chord at centre are zero. This being the case, the arch acts as a three-hinged structure under

FIG. 3.



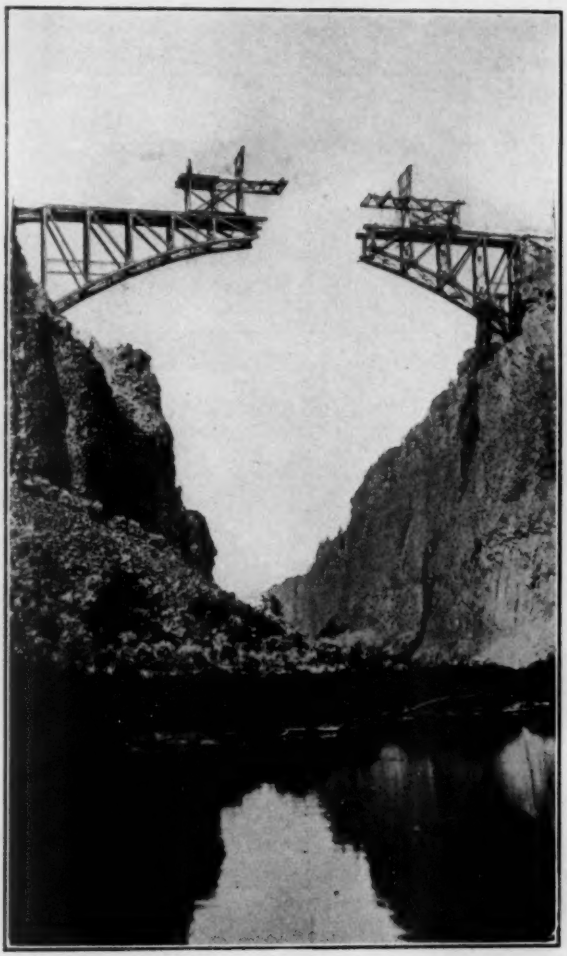
Crooked River arch. View showing completed bridge.

those conditions,—namely, with all dead load in place and at 60° F. The span was therefore erected as a three-hinged arch (Figs. 4 and 5), all dead load, or the equivalent, including the decking, was placed thereon, and at a time when the temperature was very nearly 60° the centre panel of the top chord was inserted and riveted up. The calculations were simple. The dead-load stresses were calculated as in a three-hinged arch, the temperature and live-load stresses as in a two-hinged arch, and the various results combined. This made the erection very simple and the ultimate distribution of stresses more accurate.

A two-hinged spandrel braced arch is probably the best type

to use for railway traffic, where the natural abutments permit of sufficient rise, which will often be the case where the arch type of bridge is a logical solution. This particular type of arch is

FIG. 4.



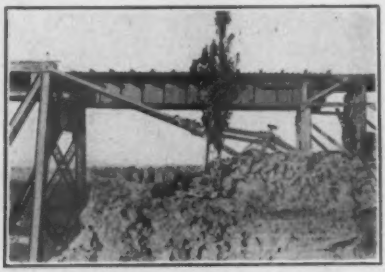
Crooked River arch under construction.

more rigid and less subject to vibration than the other types of arch, and presents the advantage of easier erection, which can then be simply performed by treating each half as a cantilever

arm held back by suitable temporary anchorages until the centre connection is made (Fig. 5).

An arch bridge is a somewhat special structure and rarely used for very long spans, except, as I remarked before, where Nature has provided abutments (Figs. 4 and 6).

FIG. 5.



Crooked River arch. Temporary anchors and adjustments.

Simple Spans.—Twenty-five or thirty years ago the system of truss most favored for long simple spans was a double intersection Pratt truss with parallel chords. Nowadays the type most used is a single intersection Pratt truss with subdivided

FIG. 6.

Berne, Switzerland. A very graceful highway arch bridge.

panels and curved top chord. Fig. 7 shows the former type being replaced by the latter in the Bismarck Bridge (see also Fig. 12). The curved top chord is an element of economy. The single system has also a slight advantage of more definite stresses. It has its disadvantages, such as, for instance, the lack of unifor-

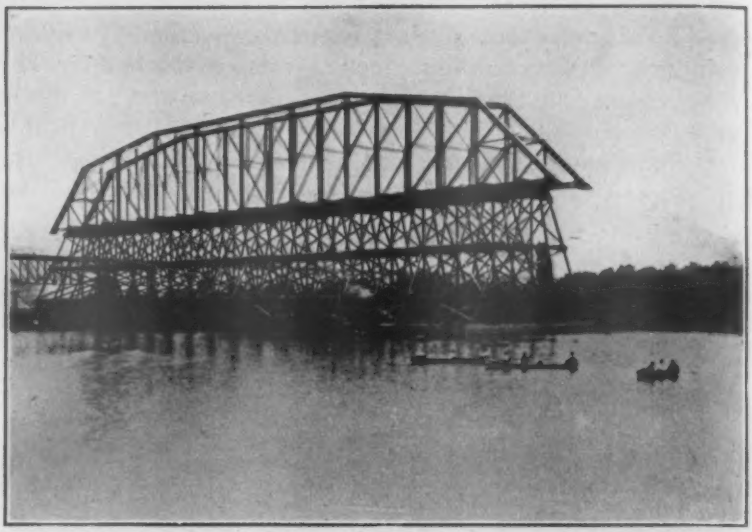
mity in deflection, about which I will speak more in detail in connection with cantilever system. There is no doubt that a bridge composed of simple truss spans is a better bridge than a cantilever system or a suspension design, chiefly because of its rigidity. This rigidity results from the fact that a load placed on one span has no lifting action on the adjacent spans, as in a cantilever system, or on other portions of the same span, as in a suspension bridge. But long simple spans must be erected on falsework or floated into

FIG. 7.

Bismarck Bridge. Replacing old spans by spans of present type.

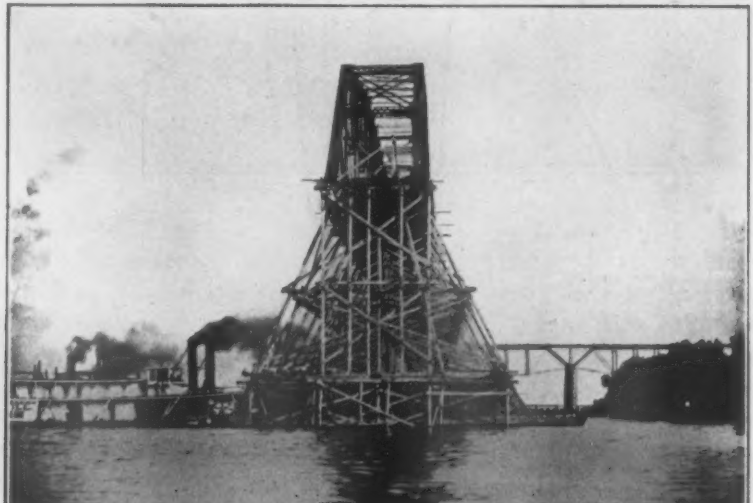
position. The first method is often inadmissible on account of the necessity of keeping the channel open for navigation, as in the Memphis and Thebes Bridges, or excessive depth of water combined with navigation requirements, as in the Quebec Bridge, or other local conditions. The floating of a span into position is not only costly but hazardous. It has been successfully performed, but is not always feasible or safe (Figs. 8 and 9). Then, too, generally speaking, a cantilever bridge is more economical for long spans. These considerations often lead to the adoption of a cantilever design in preference to simple spans. A cantilever span

FIG. 8.



Floating span into position at Louisville, Ky.

FIG. 9.



Floating span into position at Louisville, Ky.

can always be erected without falsework, although the adjacent or anchor spans must generally be erected on falsework. Sometimes simple spans are erected without falsework. Fig. 10 shows the 340-foot simple span over the main channel and Fig. 11 the 230-foot span of the Columbia River at Celilo, Ore., being erected as a cantilever.

The length of simple spans has been growing from year to year. It may be remembered that the Cincinnati Southern Bridge at Cincinnati, built in 1877, contains a simple span of 515

FIG. 10.

Columbia River Bridge at Celilo, Ore. Main span 340 feet long, being erected by cantilever method.

feet. In 1891 George S. Morison built the Cairo Bridge, containing a span 518 feet in length, single track. The Municipal Bridge in St. Louis has three simple spans of 668 feet in length, 110 feet high at centre, double track and roadways. The Metropolis Bridge over the Ohio River, if the present design is carried out, will have a simple span 720 feet long, double track. This increase is due largely to the use of higher grade materials, such as nickel or chrome-nickel steel, and to the improvement in shop and field methods.

And here we may say a few words about wind forces. In

small spans the action of wind rarely affects the main members of the span, and the wind-bracing used is calculated more to make the structure rigid against lateral motion under rapidly-

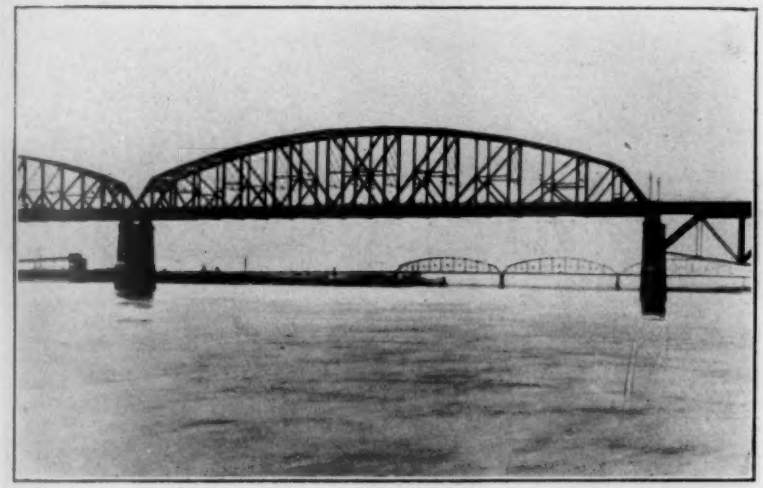
FIG. 11.

Columbia River Bridge at Celilo, Ore. One of the 230-foot spans being erected by cantilever method.

moving loads than to take care of actual wind stresses. As the length of span increases, this element of wind becomes more and more important, until in very long spans it may become as

important as the moving load. In a simple span the heaviest members, as well as the greatest height of truss, occur near the centre of the span. In other words, the resistance to wind per lineal foot of truss in a simple span is greatest at the centre of the span, and, owing to the overturning moment due to wind, grows in importance with the height. In a cantilever span the greatest height of truss and the heaviest members are near the piers, hence the greatest resistance to wind per lineal foot of truss is near the piers. This remark is sufficient to explain

FIG. 12.



McKinley Bridge across the Mississippi River at St. Louis. One of three 518-foot spans.

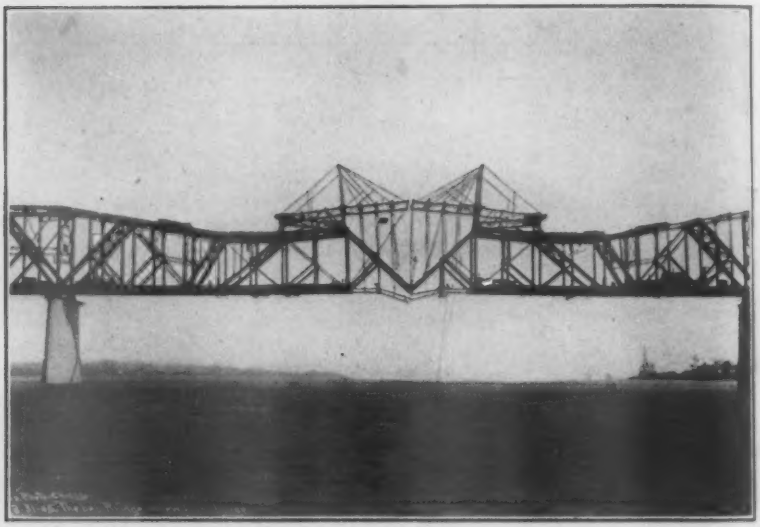
why wind stresses are easier to provide for in a cantilever structure than they are in a simple span of the same length.

I shall return later to wind forces and their importance while discussing provisions made for wind in the Forth and Quebec Bridges.

Longest Simple Span.—No hard-and-fast rule can be laid down as to the length at which a simple span becomes uneconomical as compared with a cantilever span. Generally speaking, considering the present knowledge of materials, a simple span of 700 feet may be taken as the practical economical limit, beyond which it is not advisable to go without a thorough investigation and comparison with a cantilever system. Where con-

ditions require unusual methods of erection this limit may be much lower. For instance, in the Thebes Bridge (Plate II) it was necessary to erect the 671-foot channel span without falsework (Figs. 13 and 14). A simple span would have required the addition of a considerable amount of metal, both in the span itself and in the adjacent spans, to permit of its being erected as a cantilever; this excess of metal would have been useless after the completion of the bridge, and its cost would have made the

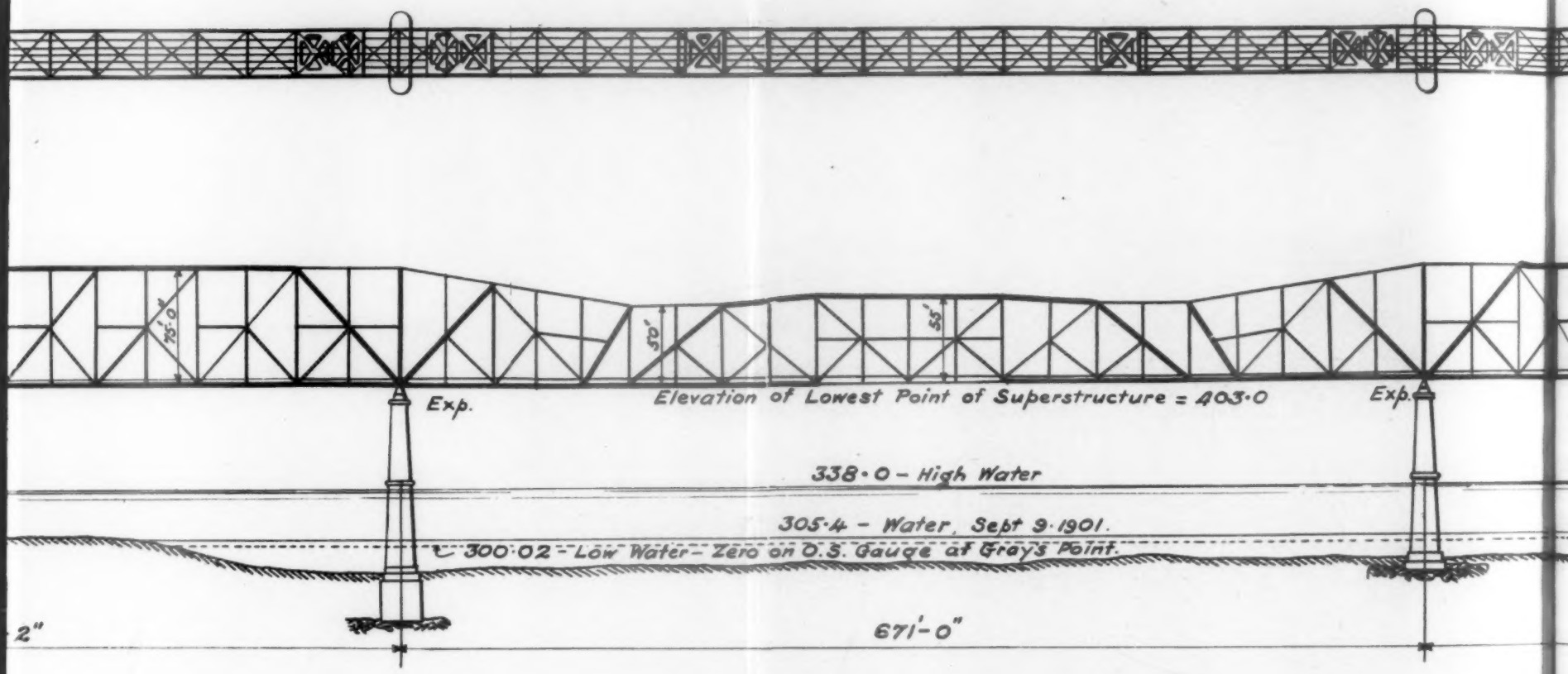
FIG. 13.



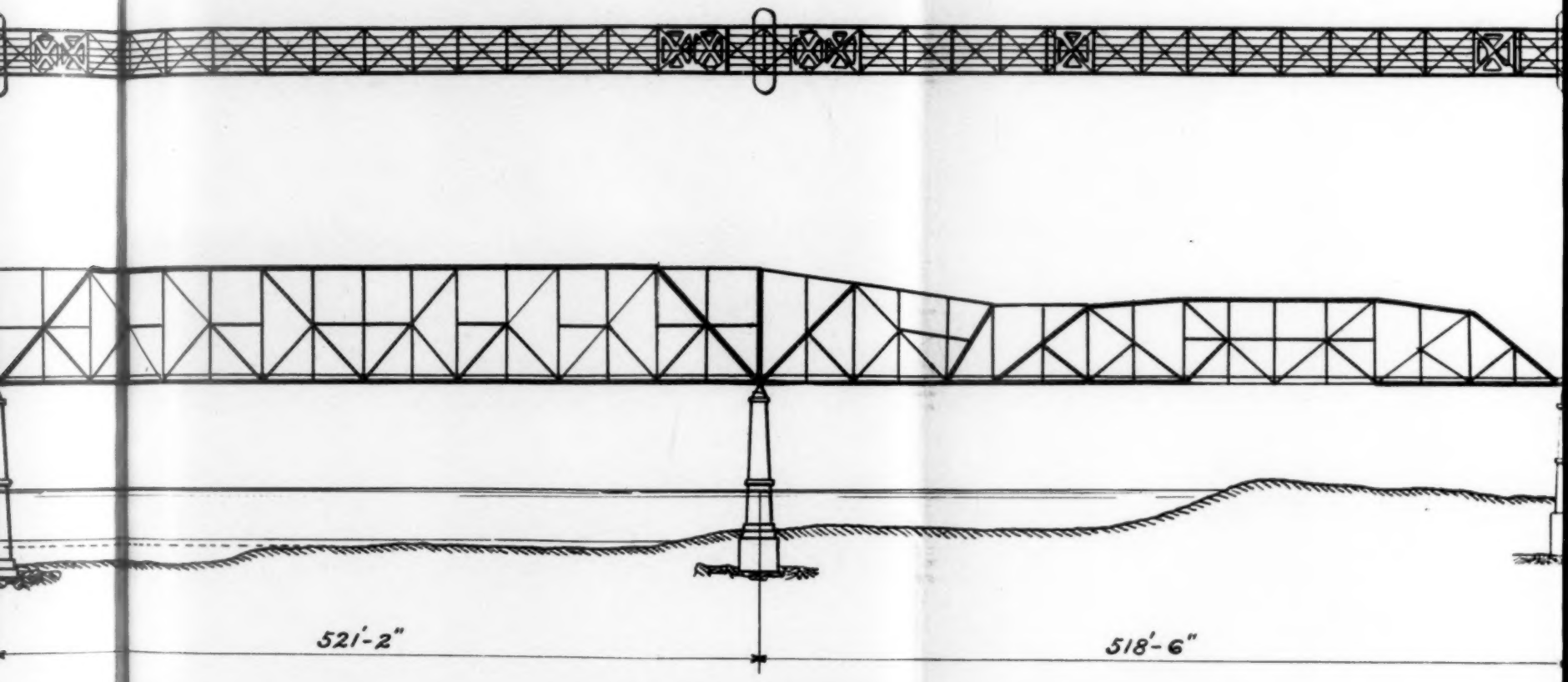
Thebes Bridge. Erecting main span by cantilever method without falsework.

bridge more expensive than the adopted cantilever design. This was shown to be true by careful estimates made at the time.

General Dimensions of Simple Spans.—In designing long simple spans the following general principles should be observed. The width, centre to centre, of trusses should not be less than one-twentieth of the span, preferably one-eighteenth. In double-track spans the width required for clearance generally governs, except in very long spans. The height at centre of span, for a Pratt system of truss with subdivided panels, should be from one-seventh to one-fifth of the length. The table below shows the proportions of the width and height to the length of span in some of the curved top chord bridges built recently:



General elevation and plan of Thebes



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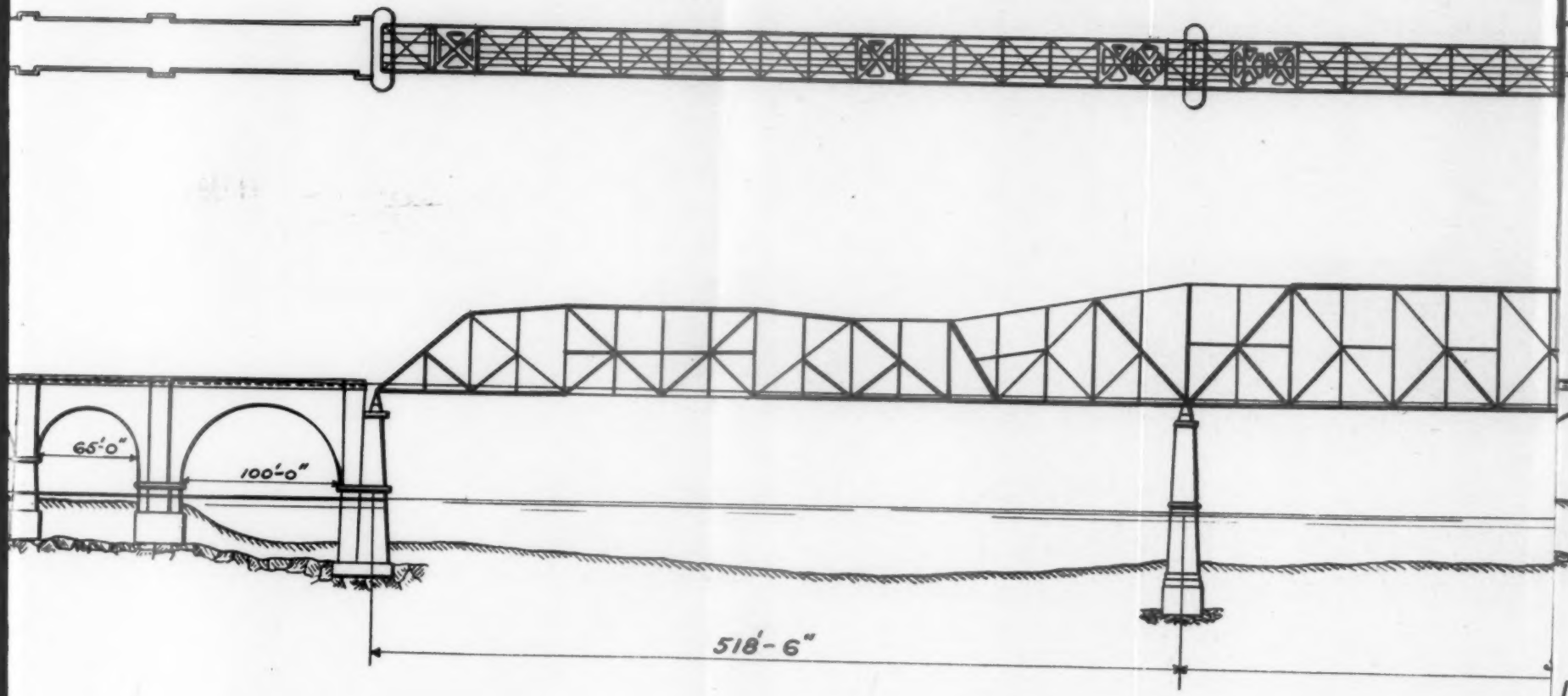
PIER II

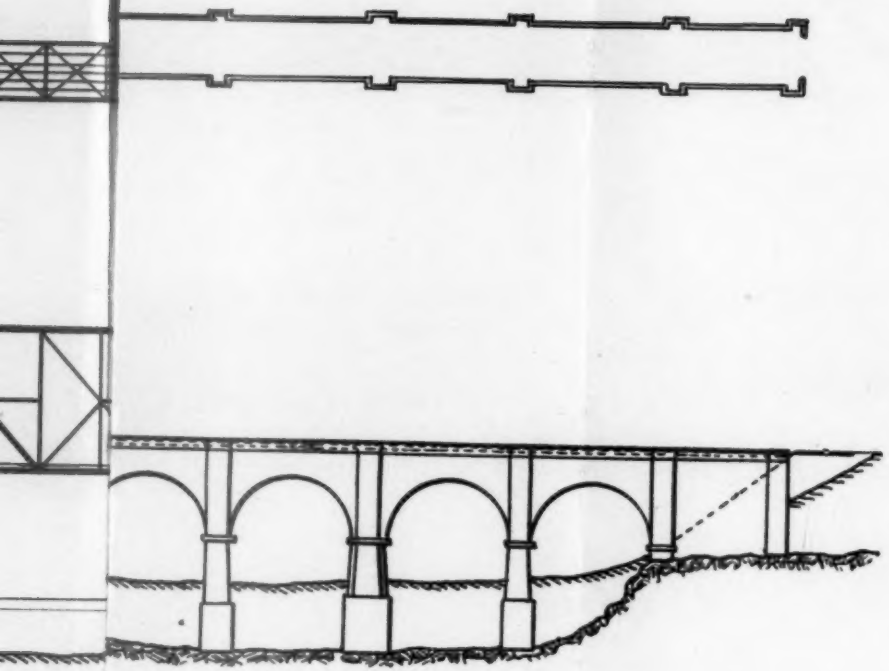
PIE

d plan of Thebes

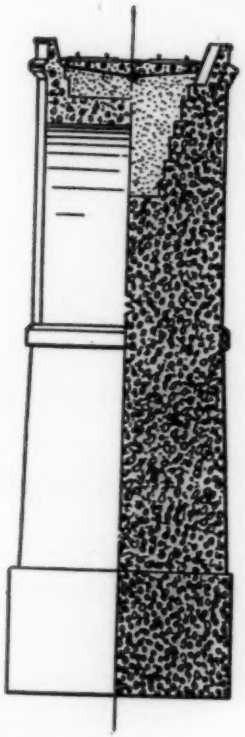


PIER VI

PIER V



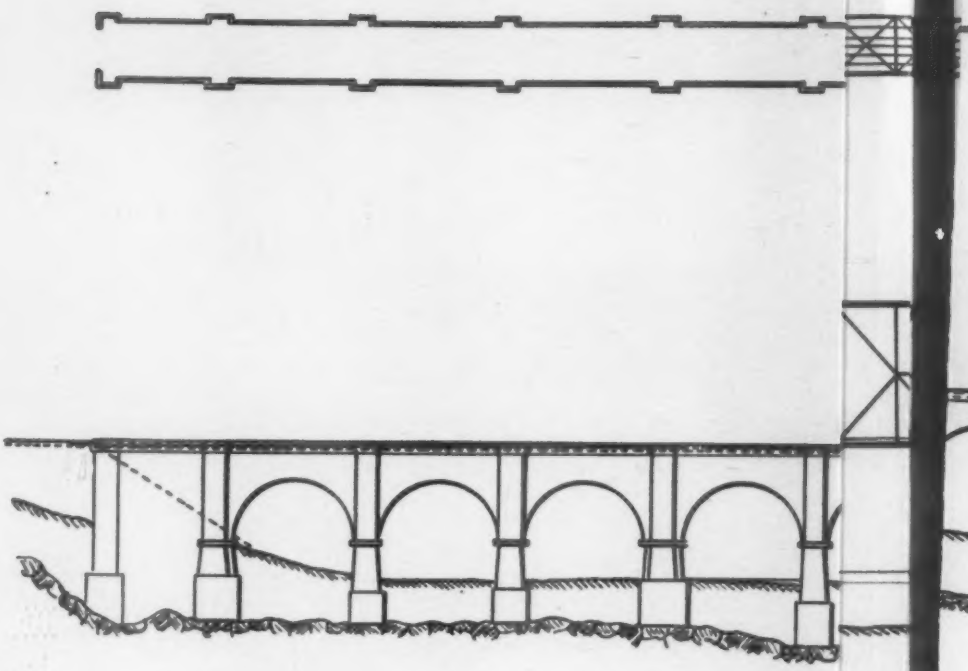
ILLINOIS



SECTION THROUGH CENTER OF ARCH

SECTION THROUGH CENTER OF PIER

ELEVATION AT



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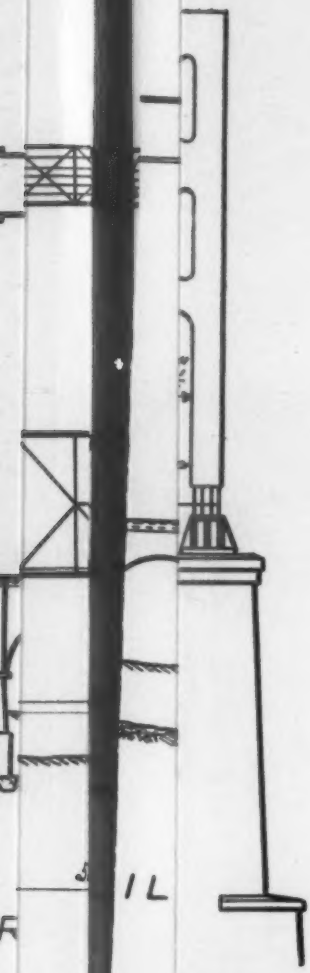

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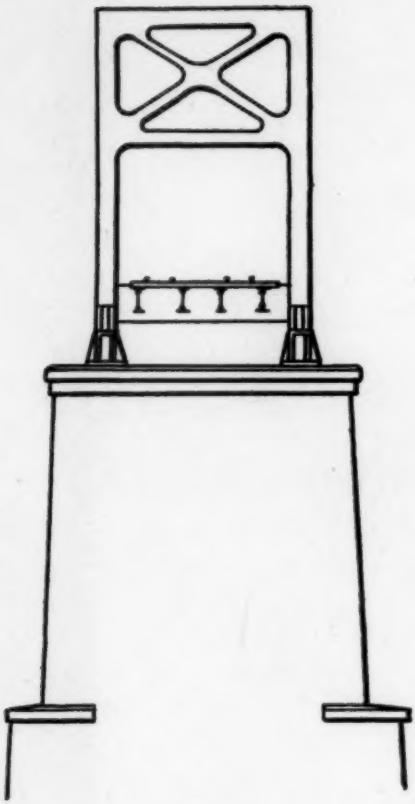


ELEVATION AT PIERS I & VI

TABLE I.

PROPORTIONS OF SIMPLE SPANS WITH CURVED TOP CHORDS.

	Per cent. ratio height to length	Per cent. ratio width to length
Municipal Bridge, St. Louis, Mo.	16.47	5.24
Cincinnati, Ohio, over Ohio River	15.41	5.60
Pennsylvania Railroad, over Delaware, Philadelphia	15.76	5.82
Ohio Connecting Ry.-Pittsburgh	14.53	5.57
McKinley Bridge, St. Louis, Mo.	15.07	5.73
Merchants Bridge, St. Louis, Mo.	14.47	5.80
Mobridge, Mo.	15.18	5.48
New Bismarck Bridge, N. D.	16.25	5.50
Quebec suspended span	17.19	....
Thebes suspended span	15.03	....
Average	15.56	....

The height at the ends should be only sufficient for an effective portal. A rigid mathematical research by Mr. Joseph Mayer, principal assistant engineer of the Quebec Bridge, leads to a theoretical proportion between the height at centre and length of span equal to .18, or somewhere between one-fifth and one-sixth, for heaviest loads and double-track spans.

Panel Length.—The best panel length is not so easy to determine. Since the economical inclination of diagonals is very nearly 45°, it would result that in a Pratt truss with subdivided panels their length should approach one-half of the height of truss. This would mean that in a truss with a curved top chord the panels in the centre should be longer than those near the end. This has been done at least in one instance, namely, in the Municipal Bridge in St. Louis. The advantages of such an arrangement are a slight economy in the weight of steel and an improved appearance, since the diagonals have nearly the same inclination throughout. The equal panels, however, present, in my opinion, two decided advantages, which may more than offset the advantages of the former system, namely, that, all panels being equal, there is a greater duplication of parts, the floor beams are all alike, except at ends, the stringers are all alike, the length of bottom chord eyebars is the same throughout; and, further, that the falsework may be built in uniform panels, and the traveller, which is usually designed with a view

to have the uprights in proper relation to the panel points, so that the connections may easily be made, preserves its relation to the various panel points as it is moved from panel to panel.

FIG. 14.

Thebes Bridge. One of the eight adjustment wedges by means of which the projecting arms were lowered and central connection made.

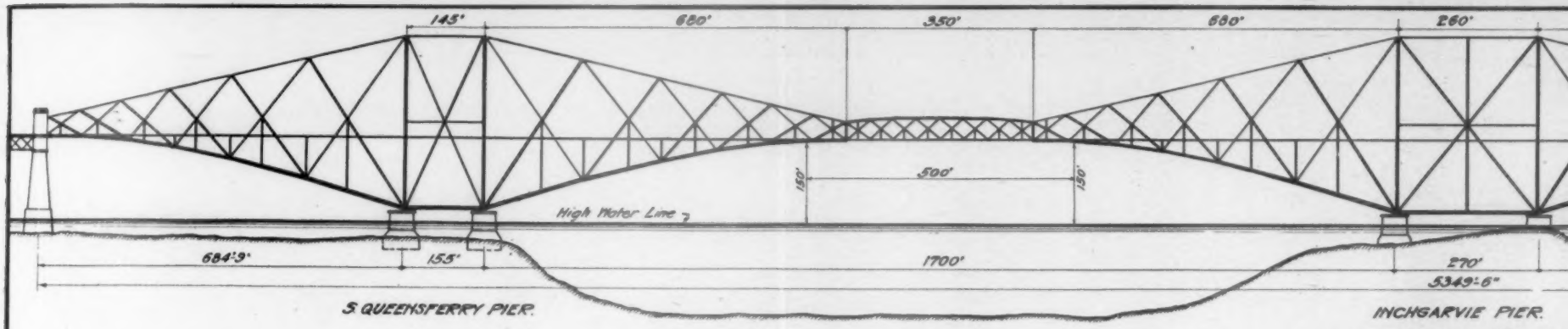
For these reasons, uniform panels should be preferred in the majority of cases of simple spans.

I have already stated that the greatest practical length of a

simple span is about 700 feet. With the use of certain known alloys of steel of greater strength than medium carbon steel this limit may become as much as 750 feet. Beyond this limit the weight of simple spans becomes so great, in comparison with cantilever spans, that the latter must be considered. A mistaken idea sometimes prevails that the weight of steel in a span increases in proportion to the square of the length. This is, in a measure, true for short spans, say 100 to 300 feet. This ratio of increase, however, is not a constant, but increases with the span. A simple span above 1200 feet in length increases in weight approximately as the cube of the length, and this exponent increases more and more rapidly until at about 2000 feet the weight of carbon steel required to carry the weight of such a span and of a moderate live load becomes infinite. For a span built of nickel-steel the weight becomes infinite when the length reaches 2700 feet. Simple spans much below those limits, even if possible, would still be very uneconomical until we get down to spans 700 feet or under.

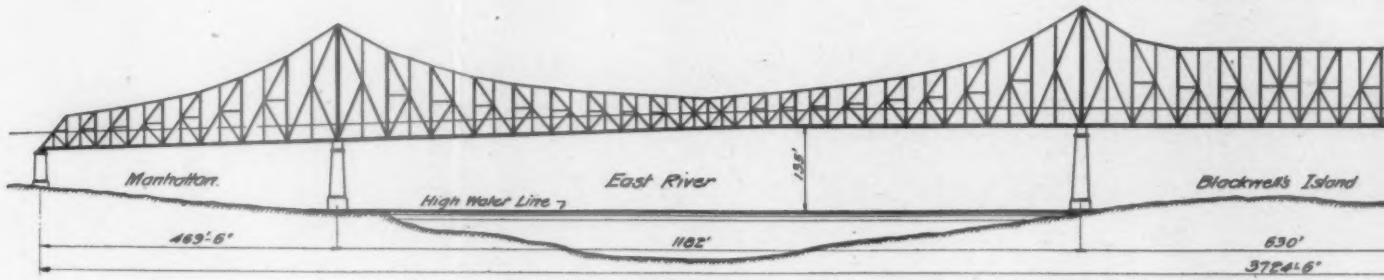
Cantilever Spans.—This leads us to cantilever spans (Plates III and IV). I mentioned two types of such spans: one without a suspended span, and the other with a suspended span. A remarkable example of a cantilever bridge without a suspended span, which may be called a semi-continuous structure, is the Blackwell's Island, also called the Queensboro Bridge, in New York. There seems to be no advantage in omitting the suspended span; on the contrary, the structure differs from a true continuous bridge over several supports only by the introduction of a hinge at the centre of the main span which transmits shears but not moments. The vibrations and deflections of each segment are, therefore, transmitted through those hinges to all the other segments. Furthermore, since the stresses in such a structure depend on deflections, there is more or less uncertainty in the calculations. I do not wish to be understood as objecting to any type of structure seriously, because of the uncertainty of calculations. In any logical construction the calculations can always be made with sufficient accuracy for the safety of the work. It is only when everything else is equal that determinate stresses should be preferred.

Let us consider the usual type of cantilever bridges, the one in which two cantilever arms support a suspended span. We



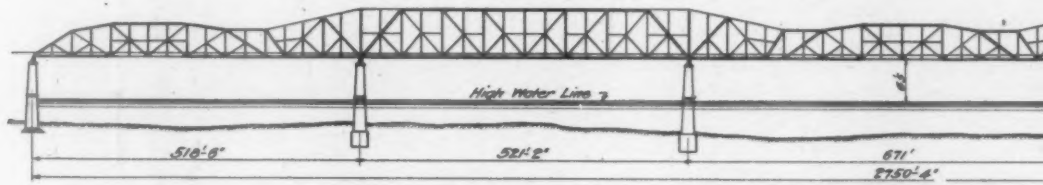
THE FORTH BRIDGE

(Near Edingburgh, Scotland.)



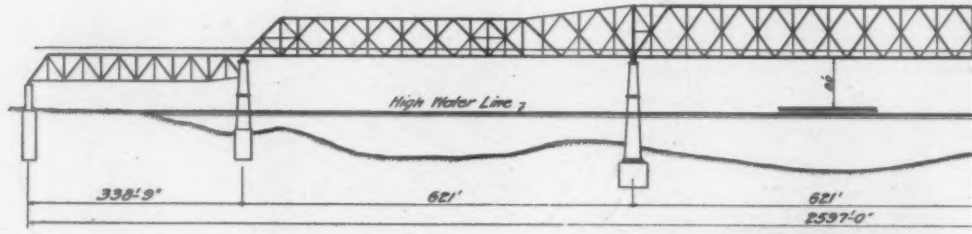
BLACKWELL'S ISLAND

(New York N.Y.)



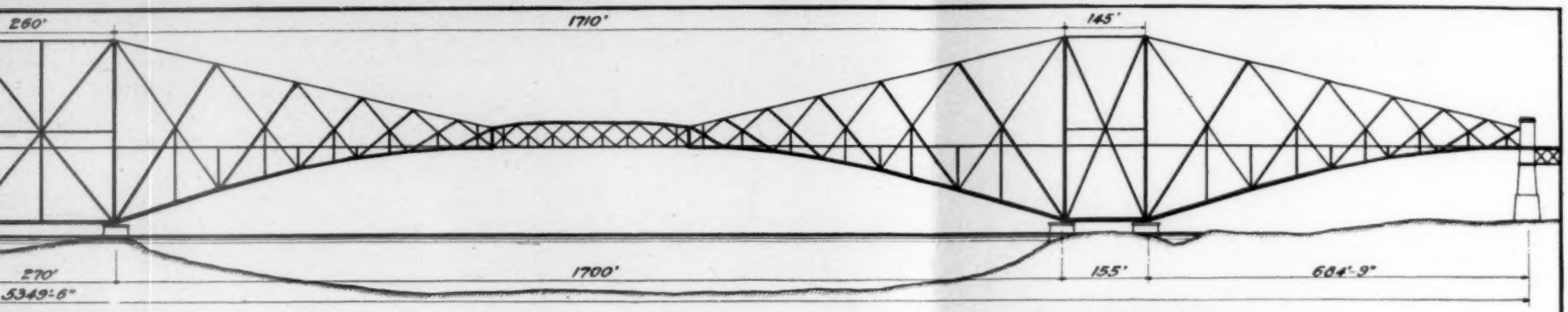
THE THEBES BRIDGE

(Thebes, Ill.)



THE MEMPHIS BRIDGE

(Memphis, Tenn)



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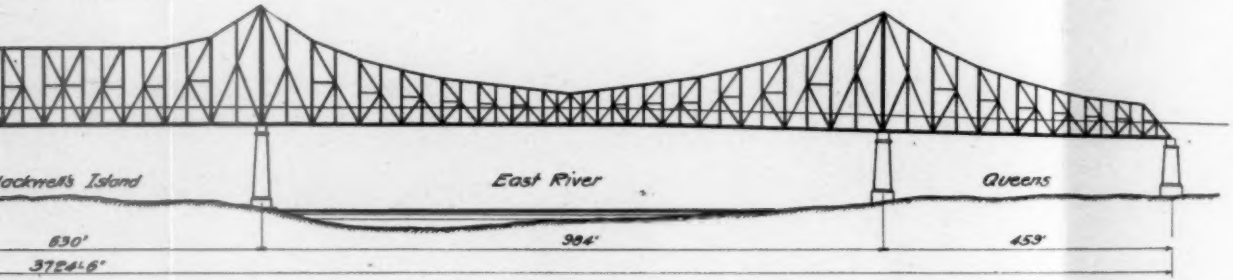

L'S ISLAND BRIDGE

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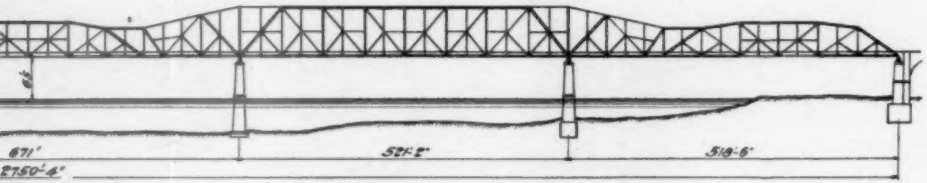

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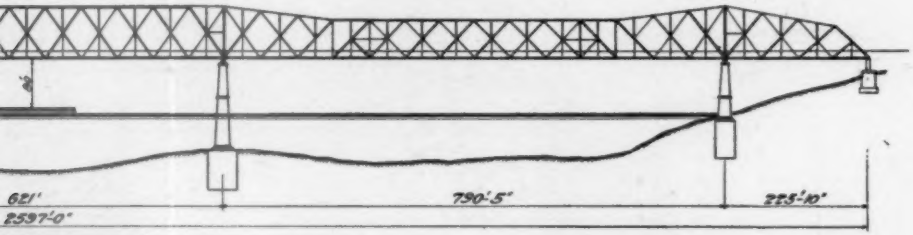

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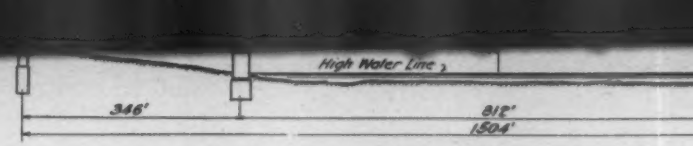
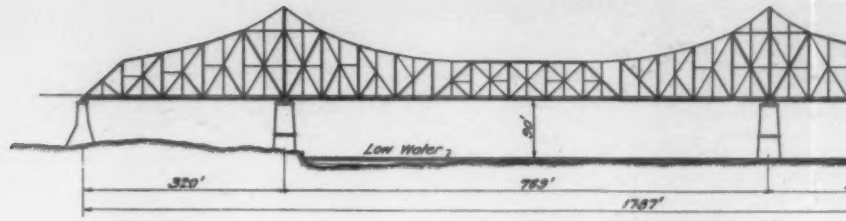
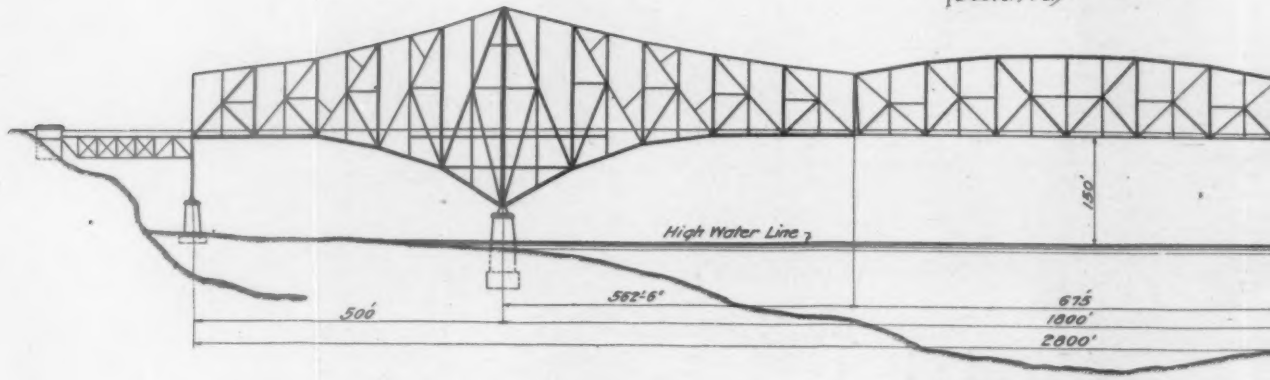


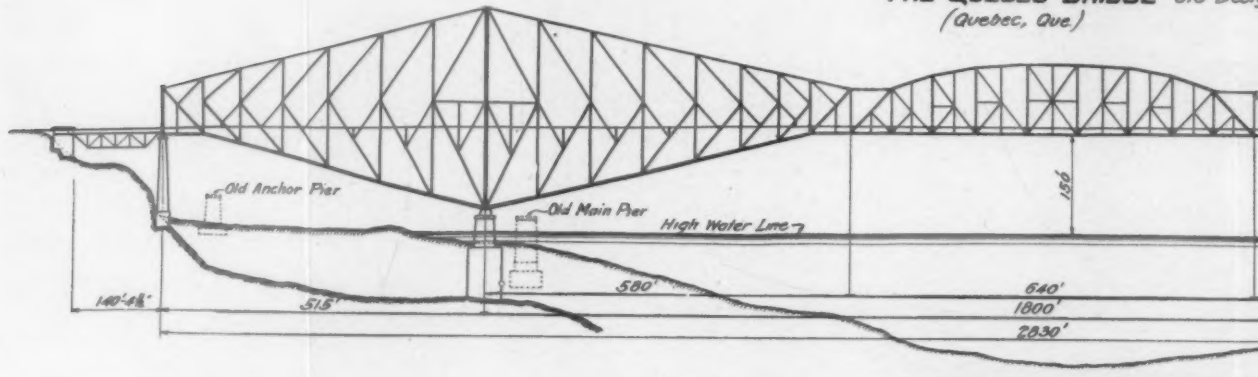
THE MONONGAHELA BRIDGE
(Pittsburgh, Pa.)



THE BEAVER BRIDGE
(Beaver, Pa.)



THE QUEBEC BRIDGE Old Desi
(Quebec, Que.)



THE QUEBEC BRIDGE New
(Quebec, Que.)

GREAT CANTILEVER BRID

SCALE IN FEET
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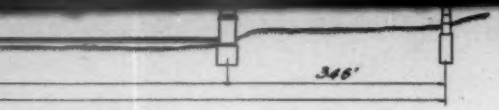

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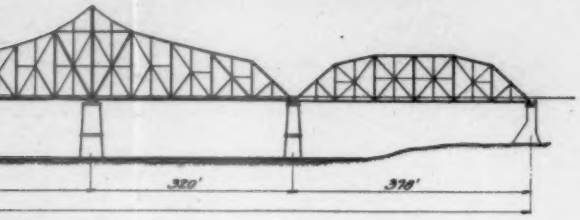

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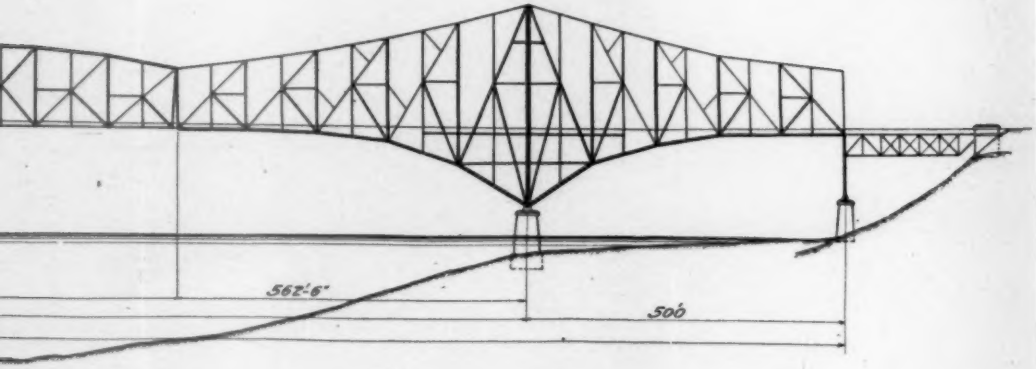
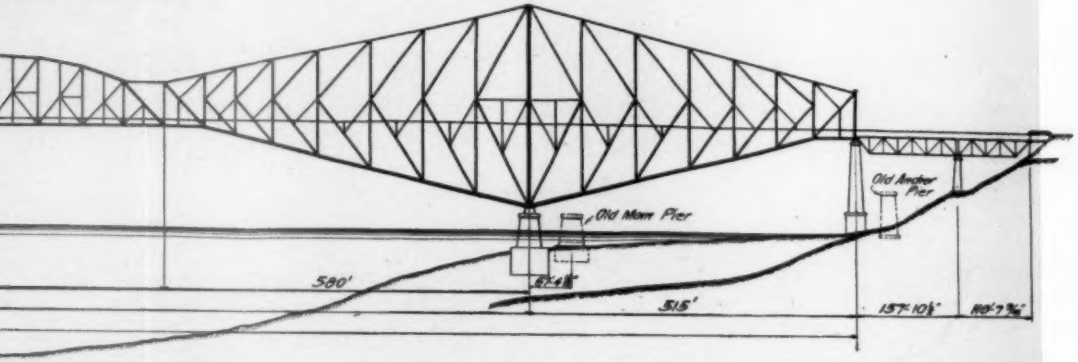


RIDGE Old Design.



BRIDGE New Design.

CVER BRIDGES

EET

may assume that in bridges requiring the construction of a cantilever span the length of the main span is usually determined by local conditions. The general dimensions to be fixed by the designer are, therefore, the length of the suspended span, the length of the anchorage spans, when these are not determined by local conditions, the height of the trusses at various points, the relative distances and positions of trusses to each other. Let us discuss these various dimensions in connection with the new Quebec design (Fig. 15). The Quebec Bridge, with its longest span in the world, has justly attracted much attention among engineers and has naturally elicited comment and criticism. It is acknowledged that a discussion of a scientific subject by professional men is often of greater value than an elaborate paper on this same subject by one individual. If I refer to some of the criticisms, let it be considered as a friendly discussion which may be of value to the profession.

General Description of the New Quebec Bridge.—The new Quebec Bridge has been finally designed with two anchor arms 515 feet long, a suspended span 640 feet long, and two cantilever arms 580 feet long. The moving loads finally adopted for the Quebec Bridge are: on each track two Cooper's Class E-60 engines, followed or preceded, or followed and preceded, by a train load of 5000 pounds per foot per track. In addition to the actual dead load of the structure, a load of 500 pounds per lineal foot on suspended span and 800 pounds on balance of bridge was allowed for snow.

Wind Loads.—The wind loads were taken as follows: A wind load normal to the bridge of 30 pounds per square foot of the exposed surface of two trusses and one and a half times the elevation of the floor (fixed load), and also 30 pounds per square foot on travellers and falsework, etc., during erection.

A wind load on the exposed surface of the train of 300 pounds per lineal foot applied nine feet above base of rail (moving load).

A wind load parallel with the bridge of 30 pounds per square foot acting on one-half the area assumed for normal wind pressure.

In the Forth Bridge the enormous wind load of 56 pounds per square foot was assumed. This load was imposed on the designers by the Board of Trade soon after the Tay Bridge

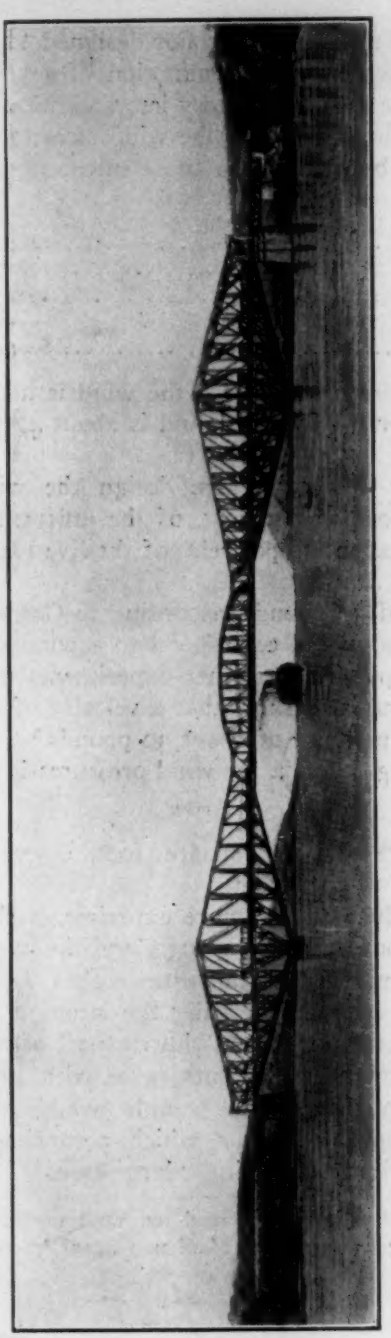


FIG. 15.

Quebec Bridge. Length of main span, 1800 feet. Clear height above high water, 150 feet.

disaster. The Tay Bridge was not designed to withstand even a 30-pound pressure. This assumption of a 56-pound wind in the Forth Bridge results in a very large addition of metal in the bottom chords through which the wind stresses are transmitted to the piers. The material in those members is distributed as follows:

Dead load	2282 gross tons
Live load	1022 gross tons
Wind load	2920 gross tons
Total	6224 gross tons

The metal here provided for the wind is nearly three times that provided for the live load, and is about 47 per cent. of the total required.

In the New Quebec Bridge design the wind pressure is equivalent to about 35 per cent. of the uniform live load near the piers and to about 20 per cent. of the live load near the ends of the cantilever arms.

A pressure of 30 pounds, according to German experiments with electric cars, would correspond to a wind of a velocity of over 100 miles per hour. Other experiments made at various times on small surfaces show that a velocity of 85 miles would correspond to a pressure of about 30 pounds.[5]

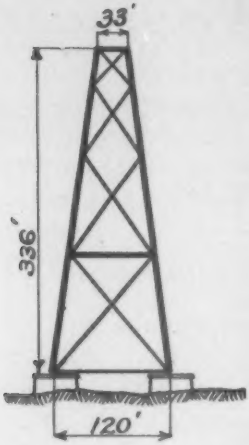
The following formula for wind pressures is generally used:

$$P = kv^2$$

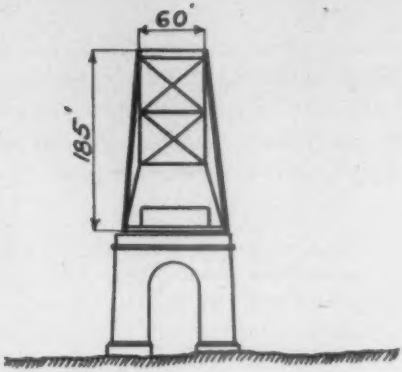
in which P = pressure per square foot, v = velocity in miles per hour, and k = a coefficient.

Eiffel's two hundred or more experiments show this coefficient to vary from 0.0026 to 0.0032, and the average is 0.0030, which he recommends. Trautwine makes $k = 0.0050$, which seems too high. But, even using the latter, a pressure of 32 pounds would correspond to a "hurricane" of a velocity of 80 miles. The German experiments agree with Eiffel's. Making $k = 0.0030$, a pressure of 30 pounds would correspond to a velocity of 100 miles per hour, which, according to Trautwine, is a violent hurricane uprooting "large trees."

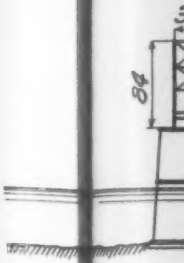
[5] See Captain Bixby's able research on wind pressure experiments in Report of Engineer Officers as to Maximum Span Practicable for Suspension Bridges.



FORTH BRIDGE



BLACKWELL'S ISLAND BRIDGE



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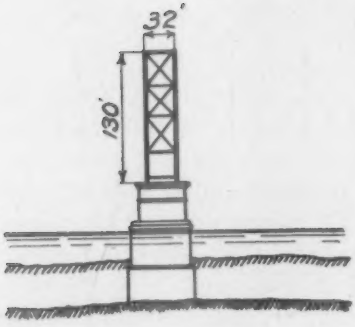
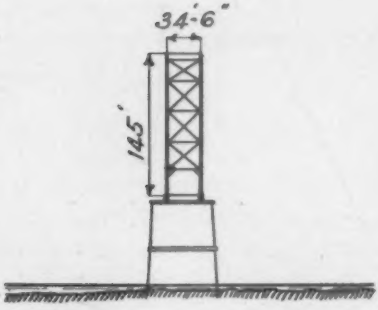
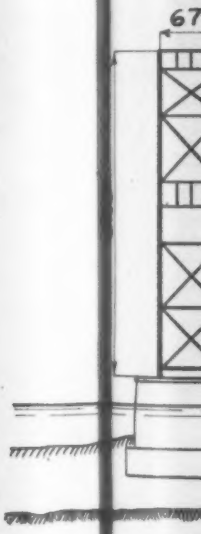


MONONGAHELA BRIDGE



BEAVER BRIDGE



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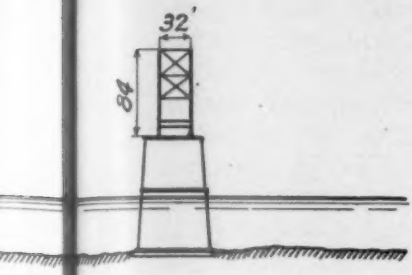
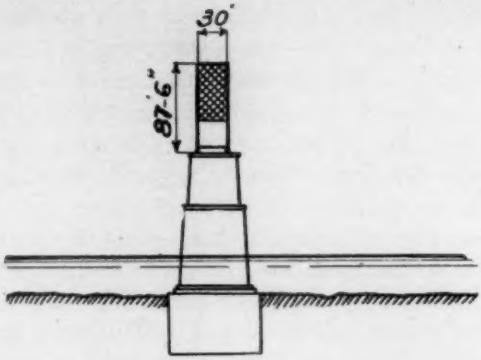
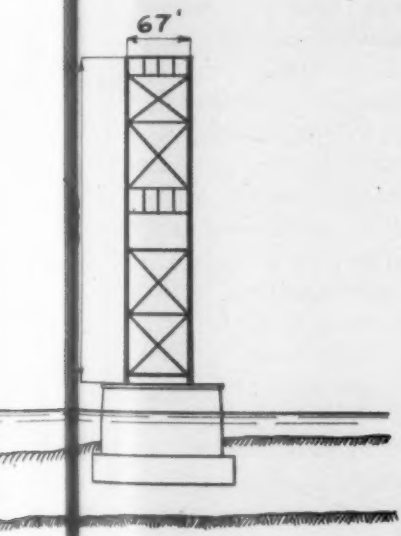


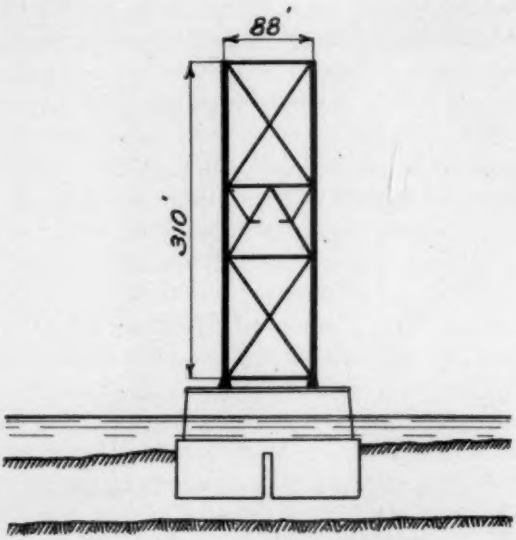
THEBES BRIDGE



MEMPHIS BRIDGE



QUEBEC BRIDGE
(Old Design)



QUEBEC BRIDGE
(New Design)

With a wind of this velocity there would be no traffic on the bridge—empty freight cars or even light passenger cars would be overturned. Velocities of over 85 miles may occur in cyclones and tornadoes over restricted areas. Such storms are very rare in Canada; but even should such an extraordinary disturbance happen, causing a wind pressure of as much as 60 pounds to be applied to the entire Quebec Bridge as now designed—the stresses in the truss members would be less than with the maximum live load and a 30-pound wind—and although the stresses in the laterals would be increased above the specification limits, they would still remain within the elastic limit of the members.

Length of Suspended Span.—The length of the suspended span does not depend merely upon the most economical distribution of material required for carrying the live loads and the dead load of the bridge after it is completed. Where there are no other considerations beyond the actual working stresses in the finished structure, the most economical length of the suspended span for a total span of 1800 feet would be in the neighborhood of 1000 feet. But to erect a simple span of such unprecedented length, either by floating or by cantilever method, would be impractical. Furthermore, the cantilever method of erecting a suspended span of even a moderate length always requires additional material, both in the cantilever arms and in the suspended span, to take care of the erection stresses. The longer the suspended span in relation to the total main span, the greater will be the required addition—so that whether it be contemplated to erect the suspended span by cantilever method or by floating into position, the length of the suspended span finds itself limited not by mere economic considerations of the finished bridge, but by either the excess of material required during erection by cantilever method, and difficulties arising therefrom, or by the difficulties attending the floating of a very long and heavy span into position. These difficulties increase very rapidly with the length of the span to be floated. In the new design the suspended span is the longest which the board considered safe to float, and it fits the entire design very well. The erection of this span by floating made it possible to design it with the view to greatest economy. Its various members will not be subjected to any greater stresses during erection than they would be in a simple span of the same length resting on two piers. It was,

therefore, possible to design it as economically as to weight as a well-designed simple span would be. It is more important to save weight in a suspended span than in an independent simple span, because each pound in the former requires several pounds in the entire structure to carry it. The importance of economy in the suspended span of the Quebec Bridge will be appreciated when it is considered that one pound uniformly distributed over the trusses of the suspended span needs 3 pounds of metal added to the bridge to carry it, making an addition of 4 pounds in all. This accounts for curved top chords in the span in question, as well as for the use of nickel-steel for the trusses thereof.

Length of Anchor Arms.—It has been pointed out that the length of the anchor arms is uneconomical—that a shorter arm would have been cheaper. It must not be forgotten that a shorter anchor arm increases the pier reactions, as well as the steel in the anchorage proper. The present anchor piers are founded on rock ledges which dip rapidly toward the river. To move them nearer to the river would have involved much more expensive foundations.

It may be remarked here that, while an addition of dead load in the main span will require several times the weight of metal to carry it, an addition of dead load in the anchor arm requires no increase of metal to carry it when there is an upward or negative reaction on the anchor pier. This is explained by the fact that any load placed between the main piers or on the main spans increases all moments and shears over all the spans, while any load placed on the anchor arm, if the reaction on the anchor pier is negative, decreases that reaction and consequently the moments in the anchor arm, but has no effect whatever on the main span. For this reason carbon steel will be used mostly in the anchor arms of the new design. The carbon steel unit stresses adopted for the Quebec Bridge are generally five-sevenths of the nickel-steel stresses, the former requiring heavier members. This additional weight in the anchor arms is a source of economy when the relative prices of carbon and nickel-steel are considered.

Height Over Piers.—An opinion has been expressed that the height over the piers of the new Quebec Bridge is not great enough for economy. Actual calculations show that for economy the height of 310 feet in the Quebec design is too great by about

20 feet for the "K" system of trussing adopted; further, that this height would have been at least 40 feet too great for the original system of the official design. The height of the Forth Bridge towers, while 26 feet higher than the Quebec Bridge, though the span is 100 feet shorter, is no doubt economical for the form of trussing adopted for it. The economical height is not only a function of the length of the span but also of the panel length next to the pier. This height should be such as to correspond to an inclination of the diagonals not far from 45°. A double intersection system with very long panels near the pier, such as adopted in the Forth Bridge (Fig. 16), would have been economical for the Quebec Bridge, except that it

FIG. 16.

Forth Bridge.

requires a system of secondary members or sub-posts, or very heavy longitudinal girders, or both, to carry the load from panel to panel. Then, too, it is well to reduce in the members the stresses due to their own weight—which in long panels become quite important. The 20-foot excess in height of the present Quebec design over what would have been the economical height is justified by the resulting reduction in the sections of the bottom chords, which are of considerable size at best.

Straight versus Curved Chords.—In long cantilever spans the bottom chords of the cantilever and anchor arms should be straight when possible. With a curved chord the joints must be made at the panel points. These joints are of great importance, as has been shown in the Report of the Royal Commission on the Quebec Bridge Disaster. They should be fully spliced

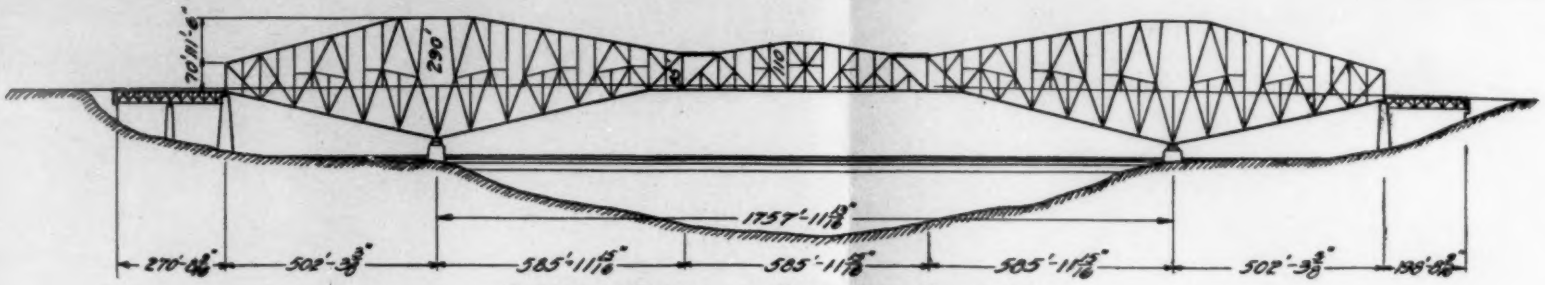
to take care of secondary stresses due to deflections of the span during erection and under the action of live load. It is advisable, therefore, to place them outside of the point of connection with the diagonals and keep them clear of gusset plates. The same objection does not exist in top chords of simple spans, which are of moderate sizes, even in the longest spans known. The economy in simple spans resulting from such curved chords is worth while and quite important, while if any economy were to result from curving the bottom chord of the cantilever and anchor spans, such economy would certainly be of little importance in comparison with the resulting disadvantages. The vertical deflections from live loads are not as great in a straight chord design as in a curved chord design. Another consideration in favor of the straight chords is that the most important, in fact the bulk, of the wind forces travel to the pier through the bottom chords of the cantilever and anchor arms and the wind-bracing, or lateral system situated in their plane. The straight bottom chords carry these stresses direct to the piers without transmitting any appreciable components to the web system of the trusses. Not so with curved bottom chords. At each joint where the chord's direction is changed a component stress is transmitted to the web. This means that while a pair of straight chords with its lateral system deflects under the action of the wind in the plane of the chords only, a pair of curved chords, by transmitting shear to the web members, causes the trusses to deflect, the windward truss downward, tending to flatten the curve, and the leeward truss upward, tending to make the curve more pronounced. The rigidity of the straight chord design against lateral deflections and oscillations is therefore greater than that of the curved chord design.

One of the reasons why curved bottom chords were used in the cantilever arms of the original Quebec Bridge design was the fact that it was the aim of that design to provide full headroom of 150 feet on a width of 1000 feet. The bottom chords of the anchor arms were then made curved also for the sake of symmetry. This width on which the full headroom will be obtained has been reduced in the new design to about 760 feet, which certainly is more than ample to accommodate navigation. Only the highest vessels will be limited to this width of 760 feet, and that only at high water.

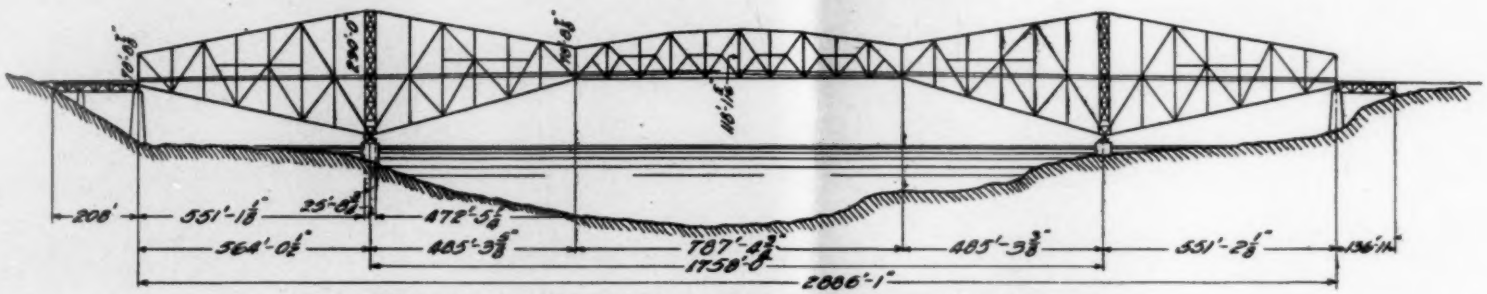
The top chord of the Quebec Bridge cantilever and anchor arms is straight. The Forth Bridge cantilever arms have straight top chords also. While there was good reason for making the Forth Bridge top chord straight, there was no serious reason, beyond a slight increase in vertical rigidity, for making it straight at Quebec. The two trusses on the Forth Bridge are in planes inclined toward each other at the top. The two top chords are parallel. Had they been made curved they could not have been parallel, since they must necessarily be situated in the inclined planes of the trusses. The appearance of tension chords having a greater distance apart at the centre of the arm than at either end would have been very bad. But there is no such reason at Quebec. The trusses are in vertical planes and the top chords could have been curved without serious inconvenience, but also without any advantage. The board considered that, aside from the additional vertical stiffness, a straight chord will present an appearance of strength which a curved chord would not do.

Relative Position of Trusses.—With regard to the distance between trusses and their position relative to each other, the trusses of the new Quebec Bridge will be in two vertical and parallel planes. The distance, centre to centre, of trusses will be 88 feet. One of the first preliminary sketches made after the board was created contemplated placing the trusses in planes inclined in the same manner as in the Forth Bridge, namely, with the tower posts converging toward the top and the bottom chords of both the anchor and the cantilever arms converging toward their respective ends. Another sketch contemplated trusses in vertical planes, but converging for the anchor and cantilever arms toward their respective ends. Both these plans would be economical in the amount of metal required in the finished bridge; but erection of a structure of this magnitude is extremely difficult, and some sacrifice of economy is necessary to make the field work as safe and easy as possible. It was during the erection that the old Quebec Bridge collapsed. The board consulted several of the best authorities on erection of large structures, and, while their opinion differed somewhat, it was decided, after much deliberation, to make the trusses parallel throughout. In doing so we had in mind not only the erection which was the principal consideration, but the greater

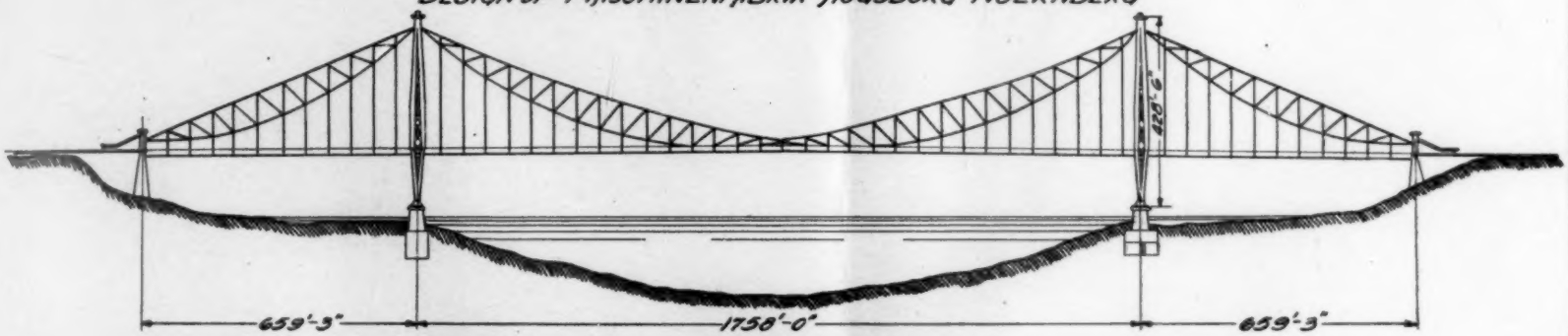
simplicity of details at such important points as the pier posts and the points of suspension of the suspended span. The connections at these points become quite complicated when the anchor arm, cantilever arm, and suspended span trusses are not all in the same plane. It would have been possible to design the bridge with trusses in two planes inclined toward each other, parallel to the axis of the bridge and passing through the end supports of each truss. In this manner all connections of truss members would have been nearly as simple as in the adopted design. Such a design was also suggested and considered. But it was soon decided that the erection of heavy members in an inclined plane of the truss would be too hazardous, and this plan was abandoned. A question may fairly be asked: Since the Forth Bridge, with its curved bottom chords, inclined and flaring trusses, has been so successfully constructed, why was it not possible to follow a similar design in the Quebec Bridge? The difference is all in the labor conditions prevailing on the two continents at the respective times of building these bridges. At the Forth Bridge 3200 to 4100 men were employed when the work was proceeding full swing; their number attained 4600 for a short period. At Quebec such a large force could not be mustered. The contractors contemplate now using approximately 400 men in the field and not over 1000 including men in the shops. In the Forth Bridge the material was all manufactured at the bridge site. By using a large force of men it was possible to build up the various members of single plates or shapes so that no heavy pieces were handled. The admirable design, consisting principally of tubes, of which there are nearly six miles in the bridge, was built up in a similar manner as boilers are made—piece by piece. The various connections were laid out in the field, plates bent to suit, drilled and riveted on. This method of procedure would be impossible in Quebec. Not only are the men not available, but while on the Firth of Forth the climate is such that work may go on at all seasons of the year, in Quebec work aloft is impossible during more than seven months in the year. Here, then, the bulk of the work must be done by machinery to save manual labor, and must be done in the shops to permit a continuous progress. The work in the field must be reduced to the minimum or to the assembling of large pieces—as large as it is practicable to handle. The Amer-



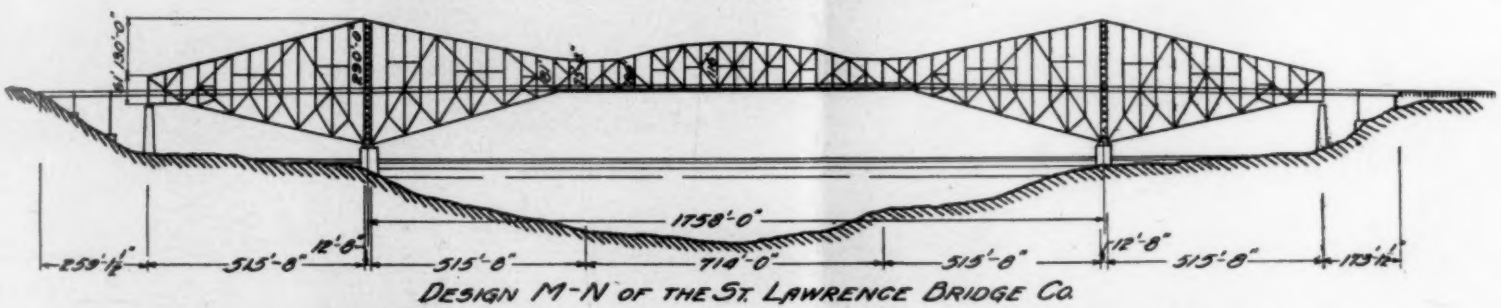
OFFICIAL DESIGN BOARD OF ENGINEERS.



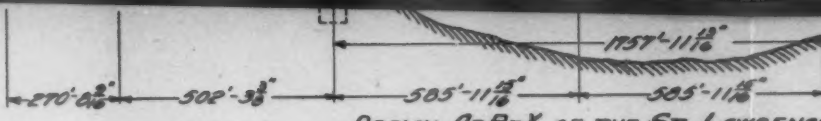
DESIGN OF MASCHINENFABRIK AUGSBURG-NUERNBERG



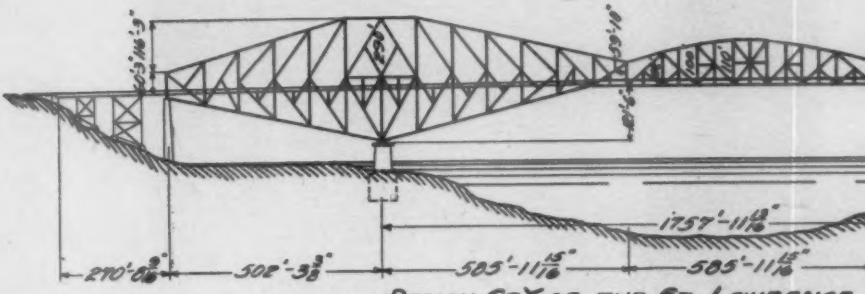
SUSPENSION DESIGN OF PENNSYLVANIA STEEL CO.



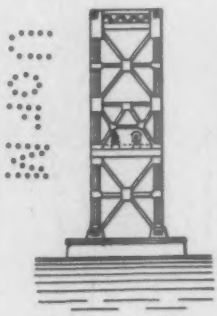
DESIGN M-N OF THE ST. LAWRENCE BRIDGE CO.



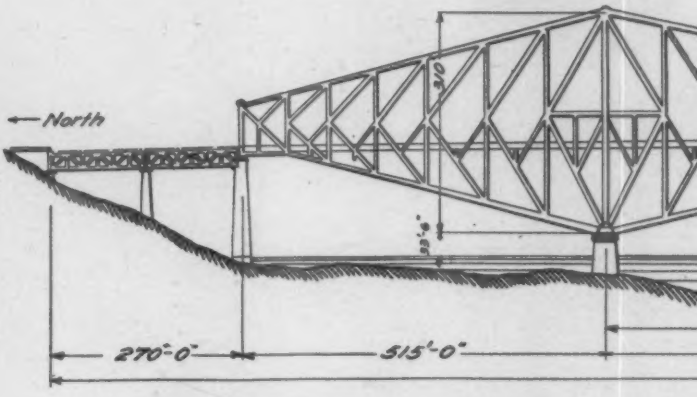
DESIGN A-B-X OF THE ST. LAWRENCE



DESIGN C-Y OF THE ST. LAWRENCE



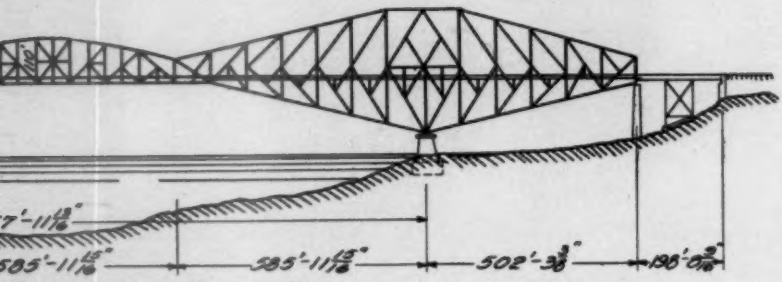
Section at Piers



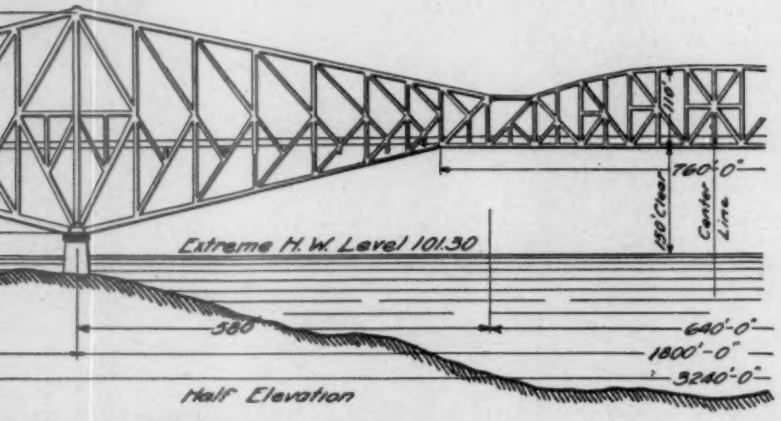
ACCEPTED DESIGN OF ST. LAWRENCE B

OUTLINE DIAGRAMS OF ACCEPTED DESIGN AND SIX
NEW QUEBEC BRIDGE OVER THE ST. LAWRENCE RI

St. Lawrence Bridge Co.



Lawrence Bridge Co.



Half Elevation

Lawrence Bridge Co.

GN AND SIX COMPETING DESIGNS FOR THE
AWRENCE RIVER, NEAR QUEBEC, CANADA.

ican type of pin-connected construction lends itself best to these conditions, but with that type the details will be much simpler and the erection much easier with trusses situated in two vertical and parallel planes.

System of Trussing.—The system of trussing was from the beginning the object of discussion and diversity of opinion among the members of the board; so much so, that before a definite agreement was reached it was decided to work up a plan which, though not satisfactory to all the members of the board, would, when detailed, give the first accurate estimate of weights, which would be also sufficiently accurate to serve as a start in designing any other plan of the same general dimensions. The plan thus detailed, though not approved, will be referred to as the official design. A discussion of the proceedings among the members of the board and the government officials, which led to the ultimate result, would be out of place here. Let it suffice that, in addition to asking for tenders on the official design, the bidders were requested to submit their own designs in accordance with specifications furnished by the board. The time allotted for preparing such designs was shorter than the time it took the board to prepare the official design; but it should be remembered that the official design furnished to the bidders information which it took months of study to prepare. Not the least important information thus furnished was the estimate of weights computed from the details of the official design.

Selection of Design.—Several designs were submitted with the tenders (Plate V); the design submitted by the St. Lawrence Bridge Company, with what may be called a "K" system of trussing in the cantilever arms and anchor arms, was finally recommended by the majority of the board and later endorsed by an enlarged board appointed by the Minister of Railways and Canals for the special purpose of selecting the best tender.[6] The main reasons for recommending the design in question are given in the enlarged board's report as follows:

(*a*) The type of design offers greater safety to life and property during erection, as well as economy and rapidity in construction.

[6] House of Commons Debates (Canada), Tuesday, April 19, 1912, vol. xlvi, No. 65, p. 5522 and following.

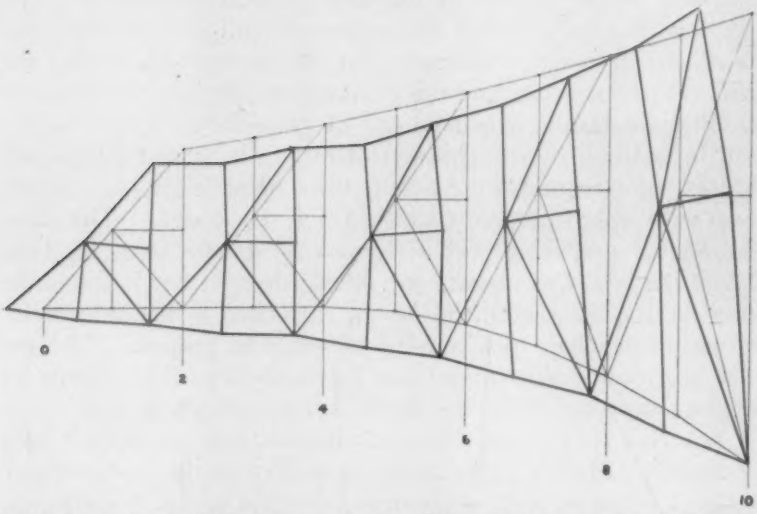
(*b*) The design contains the minimum number of secondary members and requires few, if any, temporary members during erection.

(*c*) The system of triangulation, by dividing the web stresses, reduces the members to more practical sections and simplifies the details of connections.

(*d*) The design economizes material, as shown by the calculated weights of the two designs.

(*e*) The general appearance of the structure is, in our opinion, improved.

FIG. 17.

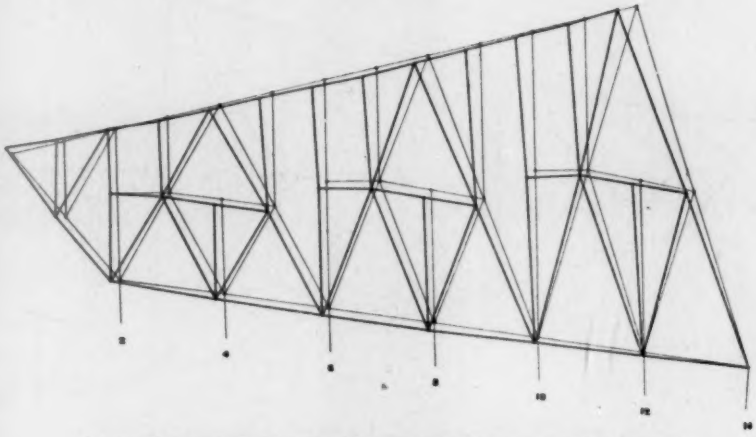


Quebec Bridge, Phœnix Bridge Company design. Deformation diagram. Live load reversed. Scale of deformation is 120 times greater than scale of truss.

There are two advantages of this "K" design which are not clearly brought out in the above reasons, and on which I wish to lay considerable stress, namely, uniform deflections and regularity of erection operations from panel to panel. The uniform deflections can best be seen by comparing the Williott's diagrams. Figs. 17 to 22 show the deflections of the anchor arm under dead load and under dead and full live load in the old, the official, and the final designs. The deformations are, of course, on an exaggerated scale. A comparison of these diagrams will show that secondary members, or those which receive their

maximum stress from partial live load only, such as the vertical suspenders carrying one panel of floor (Figs. 17 and 18), or members which carry dead load only, such as vertical sub-posts supporting the top chord, or members which normally have no stress in them, such as struts which serve to reduce the unsupported length of main compression members, are the source of local bending in the main members to which they connect. This is because the variation in length of the secondary members as the loads are applied is independent of the variation in length of the main members. For instance, a secondary member car-

FIG. 18.



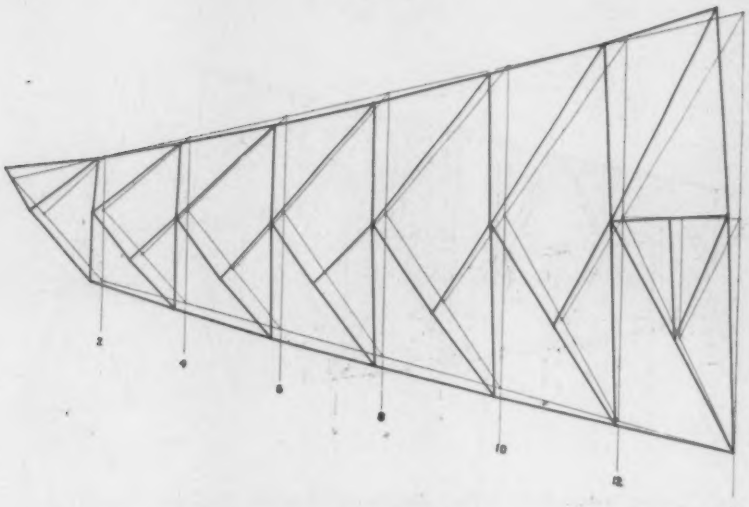
Quebec Bridge, official design. Deformation diagram. Live load reversed.
Scale of deformation is 120 times greater than scale of truss.

rying dead load only receives its full deformation in length when the span is finished, but its length remains constant under any condition of live load, while the adjoining main members compress or elongate with each application of live load. In the same manner a suspender carrying one panel of the floor, for instance, will receive its maximum elongation under concentrated live load in this panel whether the remainder of the bridge is loaded or not, while the adjoining main members will receive their maximum deformation under quite different conditions of loading. The bridges are generally designed in such a manner that the secondary stresses are either entirely eliminated or largely reduced when the main members are subject to

greatest direct stresses. This is done by determining the lengths of the various members, both main and secondary, in such a way that the truss, under the maximum load, will assume as nearly as possible the geometrical shape. This requires, however, an initial displacement of the main members, which during erection may be very objectionable.

The diagrams referred to show the situation as reversed, namely, as if the loads were applied to a truss having the true geometrical form. In order to obtain the true geometrical form,

FIG. 19.



Quebec Bridge, St. Lawrence Bridge Company design. Deformation diagram. Live load reversed.
Scale of deformation is 120 times greater than scale of truss.

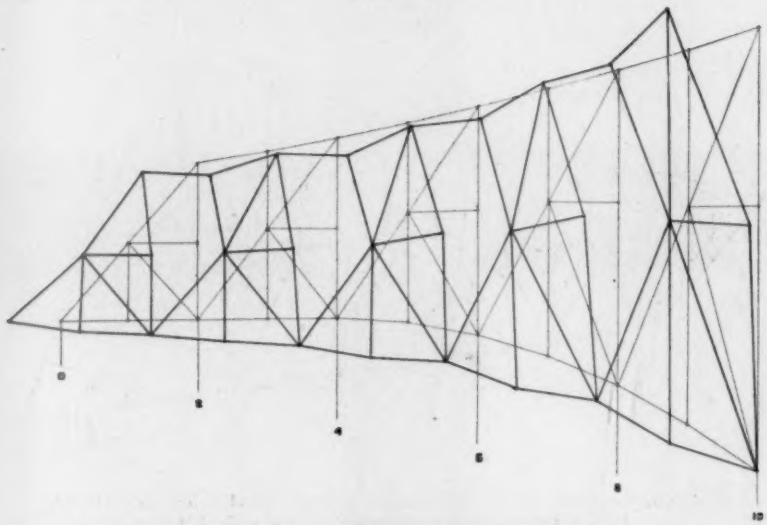
after the loads are applied, we should begin with a truss deformed under condition of no load.

The comparatively large distortions of the truss in the old design (Figs. 19 and 20) are due not only to greater unit stresses used but also to the curved bottom chord and the large number of secondary members. I have explained the reason why curved bottom chords were used in that design. Of the three designs shown in the diagrams, the new design has the least number of secondary members. It should be remarked that the same advantage could have been obtained with a double intersection

Warren truss by arranging the panel lengths in such a manner as to eliminate the intermediate vertical secondary members supporting the chords. (See Memphis and Forth Bridge diagrams, Plate III.) It would be interesting to know the extent of secondary bending stresses produced in the tubular bottom chords of the Forth Bridge by those vertical members, but unfortunately the necessary data for their calculation are not available.

The regularity of erection operations consists in the fact

FIG. 20.



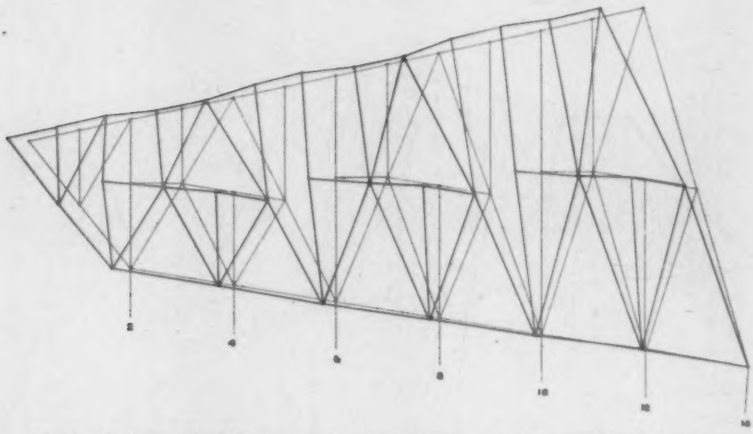
Quebec Bridge, Phœnix Bridge Company design. Deformation diagram. Dead + live load reversed.
Scale of deformation is 60 times greater than scale of truss.

that, starting from the pier, the position of members in each panel in the " K " design is just like the preceding one, and that coupling up of members in each successive panel, as the traveller moves forward, requires the same succession of motions as in the preceding one, except that pieces become lighter as the erection proceeds. Experience shows that the oftener an erection crew goes through a series of the same motions, as, for instance, in erecting a succession of simple spans all alike, the more rapid their progress becomes.

Some of the more important features of the Quebec design

will be of interest. The lateral wind-bracing has been omitted between the top chords of the cantilever and anchor arms. All wind forces are taken directly to the pier through substantial bracing between the bottom chords. This arrangement not only makes the distribution of wind stresses perfectly definite but permits the spreading of tracks to 32 feet 6 inches, centre to centre, instead of the usual 13 or 14 feet, which results in a saving in the floor system, and consequently in the entire structure. With the tracks spread, a load on one track only produces a torsion in the cantilevers, and the presence of wind-bracing

FIG. 21.



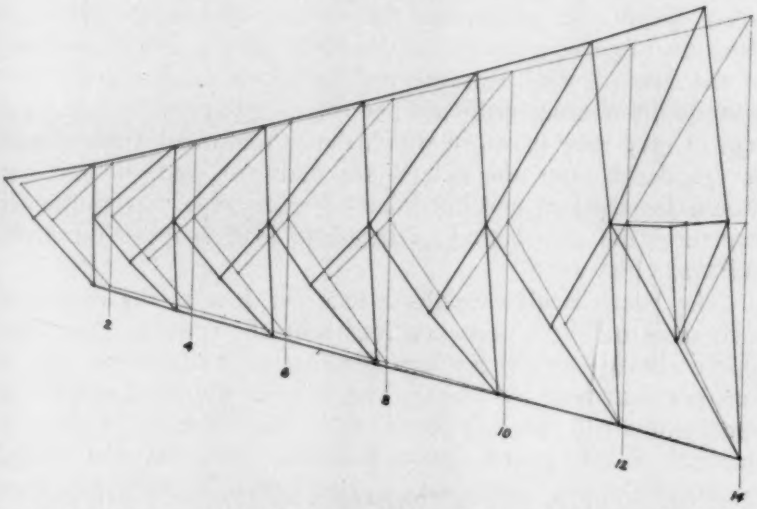
Quebec Bridge, official design. Deformation diagram. Dead + live load reversed. Scale of deformation is 60 times greater than scale of truss.

between the top chords would produce undesirable and excessive stresses which would have to be taken care of by a large addition of metal to the lateral and sway systems and to the trusses.

The floor system is of carbon steel throughout. It is, therefore, stiffer than if made of nickel-steel. The long floor beams deflect less and the secondary stresses produced by their deflection are thus reduced. Even then some of the connections of floor beams to posts had to be made by means of pins. The top chords of the cantilever arm and of the anchor arm as now designed are of carbon steel eyebars. The originally-submitted design contemplated nickel-steel plates riveted throughout for the cantilevers, and carbon steel plates for the anchor arms. By

substituting eyebars a better design is obtained and much easier erection assured, and, although nickel-steel is replaced by carbon steel in the cantilever arm, the substitution results in a saving when both the cantilever and anchor arms are considered. Carbon steel will be used in the entire anchor arm, in the top chord and pier members of the cantilever span in the top lateral system of the suspended span, in all the floor system and all sway bracing. Nickel-steel will be used in the trusses and bottom laterals of the suspended span, in the trusses except top chords and pier members, and in the lateral system of the cantilever

FIG. 22.



Quebec Bridge, St. Lawrence Bridge Company design. Deformation diagram. Dead + live load reversed.
Scale of deformation is 60 times greater than scale of truss.

arms. The anchor bars which hold down the ends of the anchor arms have been made very long to reduce bending stresses from expansion.

The suspender eyebars which support the suspended span are subject to oscillation in the plane of the trusses, due to expansion. A total expansion of 16 inches must be taken care of at these two points of suspension—besides the extension of the bottom chords under the live load. Manganese bronze bushings will be provided in these eyebars to permit of easy turning on

the pins. But, even should these fail to turn, there is sufficient metal in these eyebars to prevent overstress from bending.

Friction brakes will be installed to prevent excessive longitudinal oscillations of the suspended span under tractive forces of trains.

All latticing of compression members is designed in proportion to the sectional material of each member. The latticing is made strong enough to transmit in transverse shear 2 per cent. of the direct stress of the member.

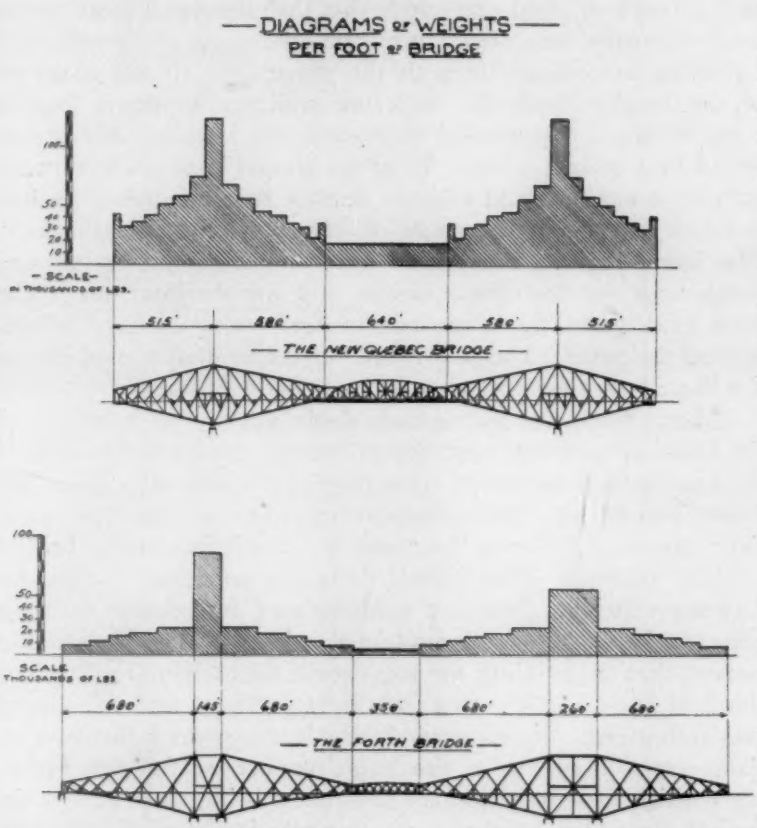
Determination of Dead Load.—After the designer has determined the principal dimensions and has designed the skeleton outline of the bridge, the next necessary step is to calculate the stress sheets and proportion the various members. Assumptions must first be made on the dead load of the various portions of the span. In simple spans and in suspension bridges a first assumption of a uniform load per foot is generally sufficient except in very long spans, in which the concentrated loads should be calculated after the details are designed, and the sections should be checked and modified if necessary. In cantilever structures the distribution of the dead load is quite far from uniform (Fig. 23).

The Forth Bridge weighs 2 tons per foot at the centre of each span and 13½ tons per foot near the towers. The new Quebec Bridge weighs 8.7 tons per foot near the centre and 38 tons per foot near the piers. The original Quebec Bridge was underestimated—the calculated dead load stresses were too small; it was to guard against a similar error that the official design of the new bridge was worked out in detail before even the system of trussing was quite agreed upon.

In calculating the weight of a span from the known weight of a shorter span it is customary to assume that the total weight of steel in trusses and bracing increases as the square of the span. This rule of thumb is sufficiently correct for small spans, not to exceed 200 or 300 feet in length, but is obviously wrong for very long spans. If it were true for all spans, then a span 10,000 feet in length could be built by providing 100 times more metal than a span of 1000 feet would require. We know that a span of such length is impossible with materials now known and that it would fail under its own load. As a matter of fact, in a cantilever system of the size of the Quebec Bridge the

weight of the steel increases more rapidly than the cube of the length. This power or exponent increases still further for longer spans until it becomes infinite for a span which is just long enough to carry its own weight only at the allowable unit stresses without being able to carry any live load.

FIG. 23.



The principal dimensions being fixed and the preliminary stress sheets calculated, the details of the structure must be worked out. Needless to say that all these determinations which I have mentioned as taking place in succession are correlated to each other, and frequent retracing of one's steps is necessary

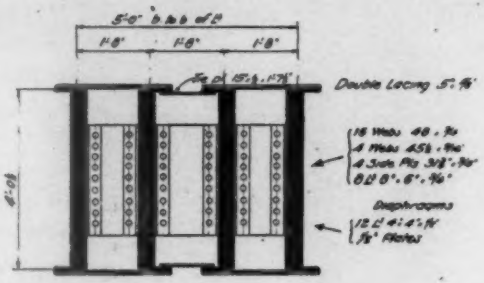
before the detail plans are matured. The general order of procedure, however, is always about as described.

Bottom Chords.—The bottom chords of the anchor and cantilever arms and their details were the subject of a great deal of study and of many tests. Little is known about bridge compression members when compared to tension eyebars. The Quebec compression chords are members of unusual size. It is only in work of great magnitude that the engineer has an opportunity to make tests on a large scale; the expense of such tests is trifling in comparison with the importance to the structure of the results obtained. It is not sufficient to know that in some bridges a compression member is still standing and is subjected to a certain stress. What we should know is how much greater stress it would take to destroy that member. Such a member may be in the stage of danger from the last straw. The board made a number of tests on models of chords and posts, both for the official design and for the final one. The tests gave generally better results for model members representing the latter. The board feels, therefore, that a good design for these heavy members has been obtained (Plate VI).

There never was any serious doubt among the members of the board as to the advisability of making the bottom chords of the anchor and cantilever arms riveted throughout without pin joints, except at the main pier bearings, to avoid excessive secondary stresses. This was done and will result in a stiffer bridge.

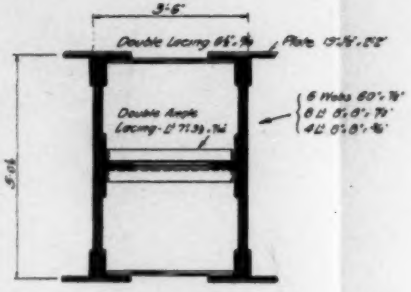
Top Chords.—The original design as submitted by the St. Lawrence Bridge Company contemplated top chords built of plates entirely. While this was approved at the time, later studies proved that by building the top chords of carbon steel eyebars there will be a slight saving of weight and cost, and the change was authorized. A tension member built of eyebars is the most reliable type by reason of the large number of full-size eyebar tests which have been and are constantly being made. It is the logical form of construction for transmission of tensile stresses. Their use reduces the secondary stresses. In a chord built up of wide plates with riveted joints, making it continuous, the secondary stresses resulting from bending due to the deflection of the span would be considerable, but owing to the uniform deflection of the "K" design they could easily be taken care of.

One of the guiding principles of the designers of the new



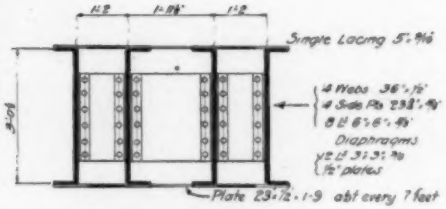
BLACKWELL'S ISLAND BRIDGE

Lower Chord L9 L10 Anchor Arm



BEAVER BRIDGE

Lower Chord L8 L9 Anchor Arm

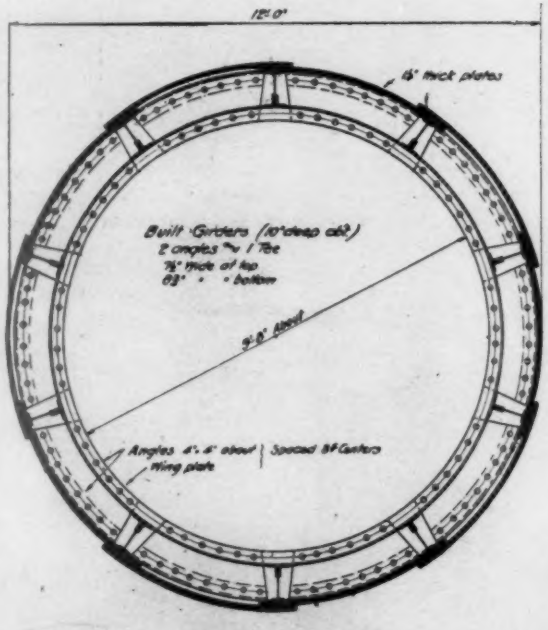


THEBES BRIDGE

Lower Chord LC3·LC4 Cantilever Arm

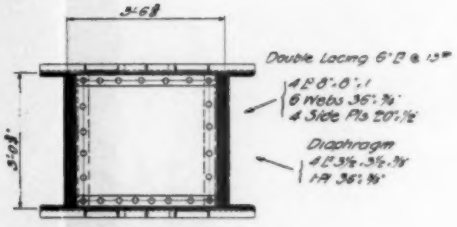
MEMP

Lower Cho



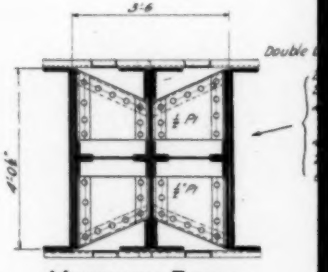
FORTH BRIDGE

Tube Section



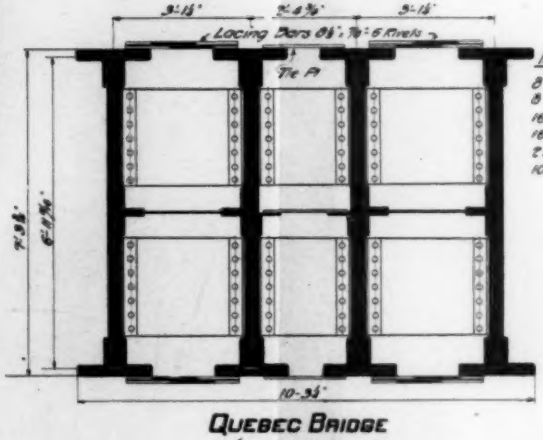
MONONGAHELA BRIDGE

Lower Chord 5-7 Anchor Arm



MUNICIPAL BRIDGE

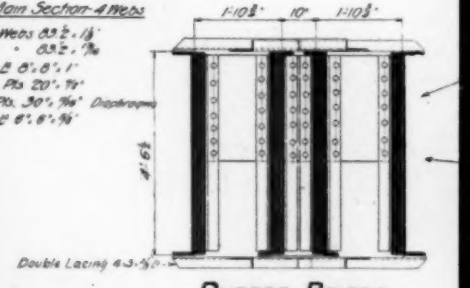
Top Chord U8·U8



QUEBEC BRIDGE

(New Design)

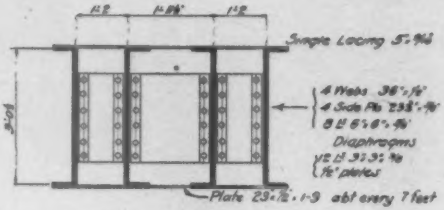
Lower Chord AL13 AL14



QUEBEC BRIDGE

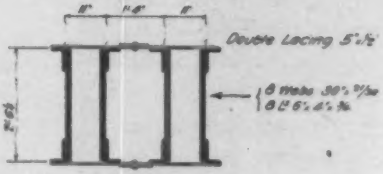
(Old Design)

Lower Chord A9 Anchor Arm



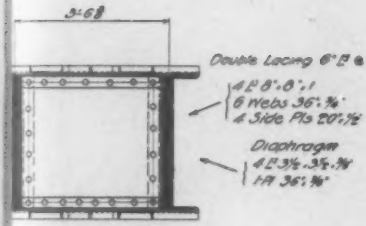
THEBES BRIDGE

Lower Chord LC3-LC4 Cantilever Arm



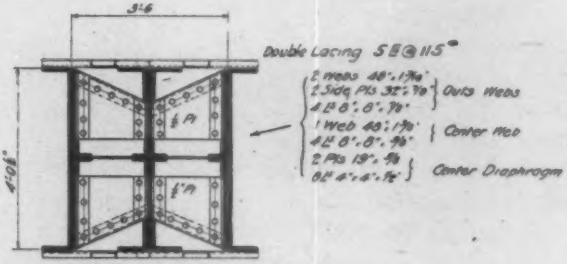
MEMPHIS BRIDGE

Lower Chord - Central Span



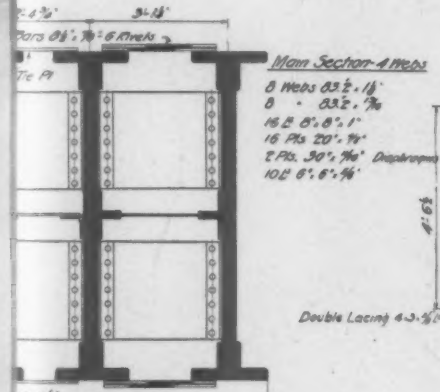
NONGAHELA BRIDGE

Chord 5-7 Anchor Arm



MUNICIPAL BRIDGE

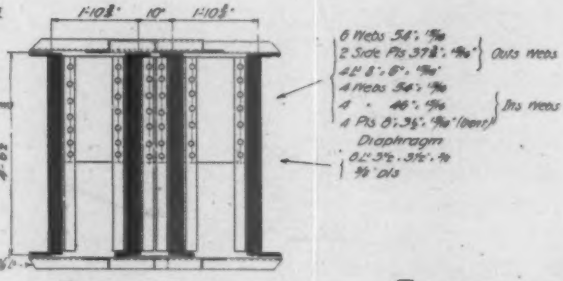
Top Chord U8-U8



EC BRIDGE

Design)

rd AL13 AL14



QUEBEC BRIDGE

(Old Design)

Lower Chord A9 Anchor Arm

SECTIONS OF L

COMPRESSION ME

SCALE IN FEET

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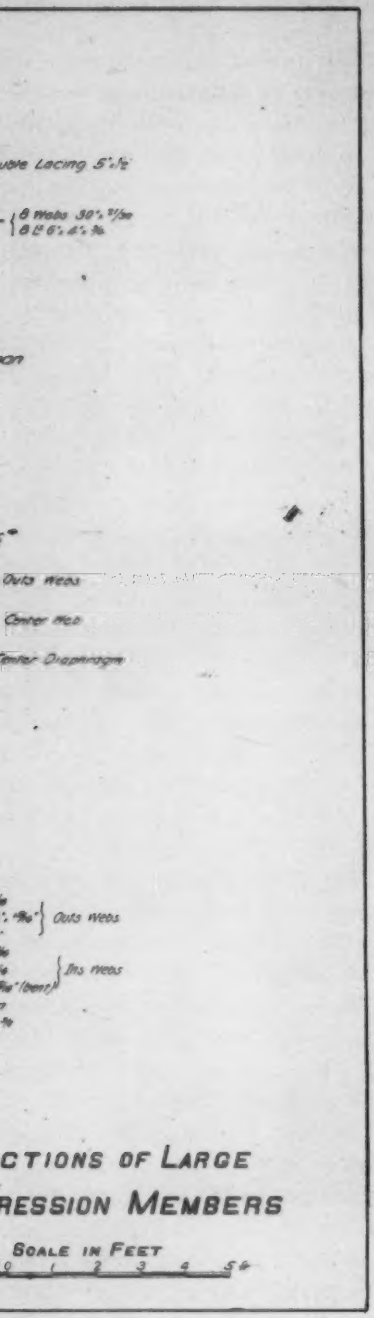


CTIONS OF LARGE
RESSION MEMBERS

SCALE IN FEET
0 1 2 3 4 5

Quebec Bridge was the elimination of untried features and experiments. In a span of this length some new features must necessarily be introduced, but they are limited to those only which grow out of the unprecedented length of span.

Suspension Bridges.—With the length of the Quebec span of 1800 feet and with the materials now at the disposal of the engineer, the practical limit of cantilever construction has very nearly been reached. In fact, if economy alone is to be considered, a cable suspension bridge would have been cheaper for a span of 1800 feet. The cantilever structure presents a greater rigidity under moving load, and this greater rigidity was the determining factor in the decision of the board to adhere to the cantilever type. Tentative plans of the suspension type with wire cables were, however, partly worked out by the board in the way of study.

The comparative rigidity of the cantilever system on one hand and the suspension type on the other may be gauged by the deflections at the centre of the span under full load.

New Quebec span, total live load	11¾ inches
A cable suspension bridge, trial design—live load only, over	2 feet
A cable suspension bridge—with 120° variation in temperature and full live load—between highest and lowest position about	7 feet

There are two reasons for the large deflections in suspension bridges: First, the deflection due to variations of temperature in the cables of a suspension span, which in a cantilever span is inappreciable; and, second, the fact that higher unit stresses are permissible in the wires of the cable than in the members of the cantilever span. The working unit stress in the wires is generally taken at from 55,000 to 60,000 pounds, while less than one-third of this is permissible in rolled carbon steel. When a moving load travels on a suspension bridge it subjects it to partial deflections which may be compared to a wave motion. This motion is greatly obviated by the use of deep stiffening trusses. The deeper those trusses are, the smaller will be the partial deflections. It is, therefore, an advantage to make these stiffening trusses as deep as practical considerations will permit. But, on the other hand, the deeper the truss the more equalizing will it perform and, therefore, the heavier will it

have to be. Each particular case must be studied in this respect, taking into consideration the relative importance of the live load which produces these local deflections, to the dead load. A suspension bridge generally consists of one main span and two side spans. There are two distinct types of side spans—one where these side spans are suspended from the cables, as in the Manhattan Bridge in New York (Fig. 24), and one where they are supported independently of the cables, as in the Williamsburg

FIG. 24.

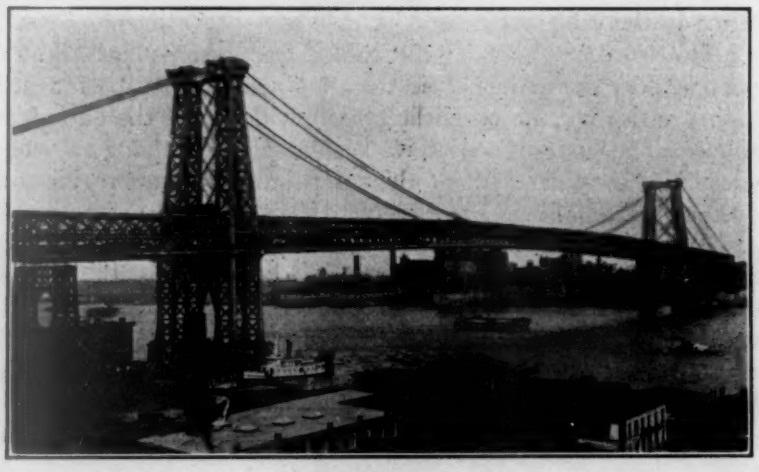
Manhattan Bridge, New York. Showing type of suspension bridge with side spans supported from main cables.

Bridge in that city (Fig. 25). There are also two types of stiffening trusses for the main span—a continuous truss, as in the Manhattan Bridge, and a truss hinged at one or more points, as in the Brooklyn Bridge. For a bridge for highway and street car traffic, even though interurban trains are to use it, the most suitable type is the one with comparatively shallow stiffening girders continuous over the main span, with side spans suspended from the cables: this because of the absence of concentrated moving loads which would be heavy enough to cause appreciable local deflections. On the other hand, a bridge for railroad use, single- or double-track, should preferably be built with deep stiffening trusses over the centre span, hinged at centre or continuous, with

side spans supported independently of the cables. It is perfectly practicable to build an efficient and economical suspension bridge for railway use if these principles are adhered to.

The main parts of a suspension bridge are the cables. These are sometimes replaced by eyebar chains. The longest eyebar suspension bridge is in Budapest and has a span of 981 feet. The longest cable span is 1600 feet, and the one built by Roebling Brothers is still giving excellent service. There is no doubt, therefore, that the wire cable has been successful for long spans.

FIG. 25.



Williamsburg Bridge, New York. Showing type of suspension bridge with side span supported independently of main cables.

It is doubtful if an eyebar chain suspension bridge of 1800-foot span would prove economical as compared with the cantilever type unless some special steel with which we have had little experience be used. The impact from moving load in the chain would be within 10 per cent. of the impact produced in the top chords of the cantilever arms, so that much higher unit stresses in eyebar chain links than those used in eyebar top chords of the cantilevers would not be justified. The allowable working stress in cables is not less than 55,000 pounds per square inch, while it is not over 30,000 pounds in nickel-steel eyebars, or a little more than one-half.

From what was said throughout this paper it is obvious that

the longer the span the greater the need of materials of high resistance. For plate girders and short spans ordinary medium steel does very well and is used exclusively; for longer spans, beginning with 400 feet, alloy steel, such as nickel-steel, nickel chrome, vanadium, etc., may be used to advantage, this advantage increasing with the length of span. The practical limit of cantilever system for known materials is reached at about 2000 feet for a railroad bridge. For longer spans, suspension bridges should be used, and are made possible by the high resistance of wire cables. The practical span limit of a wire cable suspension bridge has been calculated at 4335 feet, assuming a working stress in the cables of 60,000 pounds per square inch.[7]

The breaking load of the cables was assumed at 180,000 pounds per square inch. If an alloy wire be used of a still higher resistance the practicable limit will exceed the one given above. The limit of length of a cable alone without any load except its own, stressed at 60,000 pounds per square inch, is 15,160 feet.[7] This assumes the versed sine of the cable to be ⅛.

An eyebar chain of alloy steel, such as now in use, should not be stressed beyond 30,000 pounds per square inch. Assuming this stress and a versed sine of ⅛, the limit of length of such a chain will be 7010 feet. Hence, the limit of span length of an eyebar chain suspension bridge to carry live loads would be considerably below that of a cable suspension bridge.

The suspension design lends itself better to graceful treatment than a cantilever bridge, and may often be preferred for ornamental highway bridges even where a cantilever were to make a cheaper bridge.

Considering the purely utilitarian structures, such as the majority of railroad bridges, the present knowledge of metals and its alloys, and the present loadings, we may sum up the various types of large bridges as follows:

For spans up to 750 feet.....Simple spans.
For spans from 650 feet to 2000 feet...Cantilever spans with suspended span.
For spans from 1500 feet to 4000 feet..Cable suspension spans.

Arch spans have their place only where natural conditions are favorable, or for ornamental bridges.

[7] Report of Board of Engineer Officers (U. S. Army) as to Maximum Span Practicable for Suspension Bridges, 1894.

Chain suspension bridges may be used for ornamental highway or city bridges, but for railroad service and for spans below 1500 feet the cantilever is to be preferred as giving a stiffer and generally a cheaper structure.

It will be noticed that the above limits overlap. Local conditions in each particular case will be considered in deciding whether a span between 650 feet and 750 feet should be simple or cantilever, or whether a span between 1500 and 2000 should be a cantilever or a suspension span.

Secondary Stresses.—I shall not dwell long on this latest addition to bridge calculations. That secondary stresses exist is a fact. They may be from three sources:

First.—Weight of member.

Second.—Temperature.

Third.—Bending from loads.

In the new Quebec design all secondary stresses were calculated and taken care of, but as a result of tests made by the Quebec Board, the stresses in tension members due to their own weight will be neglected. It is quite possible that if similar tests could be made for other secondary stresses it would be found that the metal adjusts itself to a large extent in such a manner as to reduce the importance of those secondary stresses and their influence on the elastic limit of the member. Personally, I feel there is a tendency at present to overrate the importance of secondary stresses. They should, of course, be considered in designing a structure; it should be the aim of the designer to reduce these secondary stresses to the minimum, but excessive refinement should be avoided, and unit stresses for direct loads should be made low enough to include these secondary stresses where they may exist.

Materials.—The proper selection of materials for a structure is an important part of the design. The ordinary commercial steel will do for rough plate girder work, but for large bridges a metal of higher quality should be used. The metal or alloy should have a high elastic limit, a high ultimate stress, and possess sufficient ductility, which is characterized by the elongation and the reduction of the cross-section of specimens tested, to allow its being worked in the shops without fear of injury. Here, perhaps, climatic conditions should be mentioned. Intense cold makes steel brittle. This is shown by the greatly-increased

number of rail fractures during severe winters. The use of high carbon steel should therefore be avoided in northern climates. The behavior of the various alloys in freezing weather needs yet to be studied.

In all that precedes I have endeavored to avoid speaking of matters which are usually given in text-books. I have also avoided mathematical deductions, leaving them to better mathematicians, and I have attempted to deal with this vast subject from a practical standpoint only. When the final report of the Quebec Board is published it will give in detail what I have merely been able to outline. Numerous most interesting tests and mathematical analyses have been made and will be published in the course of events. It will then, perhaps, be realized, even by the members of the engineering profession who had no opportunity to fully design a very long span, that, while it is very easy to draw a diagram and a few of the principal details, it takes months of study, of retracing one's steps, of tests and calculations to make a complete design and to learn that the preliminary diagrams and sketch details must often be changed entirely to make a practicable and an efficient structure.

Dynamics of the Electron. A. SIGNORINI. (*N. Cimento,* iv, Ser. 6, 257.)—This is an attempt to develop a mathematical theory of the motion of an electron in an electromagnetic field without subjecting the electron itself *a priori* to any kinematical linkage. The only distinctive property utilized is that its dimensions are infinitesimal with respect to those of the field. Following Larmor's mechanical conception, the electrons are considered as systems possessing a finite number of degrees of freedom. In the Lagrangian function of the mechanical model (excepting the connection between kinetic and potential energy) Abraham's assumption is made, in which only electrokinetic elements appear, such as the distribution of charges and currents, and retarded relative potentials. Levi-Civita's asymptotic expression is taken for the retarded potentials, and the previous history of the motion of the electron is thus eliminated. For any given position of the electron and for a given distribution of currents and charges the motion of the electron, which has 12 degrees freedom, is defined by a system of 12 ordinary scalar differential equation of the second order, in which the time appears as an independent variable.

THE DIELECTRIC PROPERTIES OF NON-CONDUCTORS.[1]

BY

PHILLIPS THOMAS, Ph.D.,

Westinghouse Electric and Manufacturing Company.

THIS paper presents the results of an attempt to find some connection between the various electrical properties of certain insulating materials, and to secure evidence as to whether or not general relations hold between such properties of non-conductors as a class. The plan was to select, by preliminary tests, a few substances that differ greatly in specific inductive capacity, and to make extensive and accurate tests on the materials chosen. The data thus found were to be reduced to some form permitting ready inter-comparison.

The materials chosen for test were mica, paraffined paper, celluloid, and ice. The dielectric constants of these substances range from about 4 to about 100, when measured by alternating current of high frequency. The tests were made upon condensers having these materials as dielectrics, and were as follows:

(1) Tests of capacity and power-factor at high frequencies.

(2) Tests of insulation resistance by direct current, and of capacity on very short times of charge.

(3) Tests of the breakdown strength of portions of the dielectrics, removed from the condensers.

(4) Tests upon the change in capacity, due to varying the direct voltage applied to the condensers.

The condensers tested, with the exception of that in which ice was the dielectric, were parallel plate condensers of the ordinary type, and consisted of a number of sheets of dielectric, separated by sheets of conducting material, the whole being impregnated with paraffin and placed under pressure until the paraffin was nearly all crowded out. The mica condenser had not been so treated, however: in this case the leaves had been simply stacked without permanent compression and without paraffin.

[1] Communicated by the author.

Each of the condensers had a fairly large capacity, that of all but the ice condenser being of the order of 1 microfarad. Because of this high capacity, and because of the large difference in power-factor between the standard condenser and the condensers tested, it was possible to use a simple modification of one of the Wien methods of measuring capacity and power-factor. The modification employed consisted in balancing the test condenser against an exceptionally good mica condenser. Adjustment to equality of power-factor was made, as a rule, by varying a resistance in parallel with the standard condenser: the resistance was used in series when the parallel value called for a very large resistance to effect a balance, as then the residual constants of the coils used became too large to be neglected.

The use of a Vreeland oscillator[2] made it unnecessary to correct the form-factor of the alternating voltage applied to the bridge circuit. Briefly described, this instrument causes resonating at its natural frequency to be continued indefinitely in a circuit containing a variable self-induction and a variable capacity. The exciting apparatus is a mercury vapor tube with two anode terminals, and the oscillating circuit is connected as a shunt to these two anodes, which form the common positive terminal of the direct-current mercury arc. The frequency of resonation may be varied by changing the capacity of the condenser, or by connecting the two reactive coils either in series or in parallel. The oscillating current is very approximately of true sine form. The self-induction and capacity in the oscillating circuit were measured, and had such values that the natural frequency, f, was given by the expression,

$$f = 1082\ (c)^{-\frac{1}{2}},$$

where c is expressed in microfarads, and the reactive coils are in series. The frequencies calculated by this expression were tested by connecting a telephone receiver to the terminals of a small coil of wire loosely coupled inductively with the oscillator circuit, and comparing the frequencies by the method of beats with those of a set of standard Koenig forks. The error made in these calculated frequencies was not more than 1 per cent.

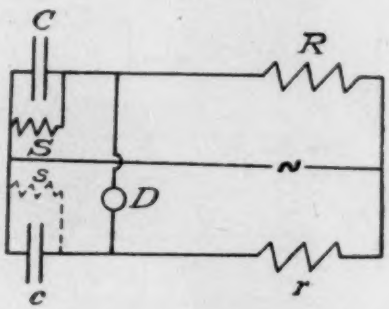
The complete theory of the Wien compensated bridge

[2] Vreeland, *Phys. Rev.*, vol. 27, No. 4, 1908.

methods for the simultaneous measurement of the capacity and power-factor of condensers has been given by Grover.[3] When the capacities compared are large and have very different power-factors, the corrections for the small capacities and self-inductions in the measuring resistances will have a negligible effect upon the accuracy of the results.

The condenser used for the standard in all the tests was a Leeds & Northrup mica condenser, serial number 13,944. The condenser was supplied with a certificate from the Bureau of Standards which gave the power-factor as quite negligible for

FIG. 1.



the larger capacity values; the capacity change with frequency was also stated as extremely small. This condenser was compared with a large air condenser by the Wien method adapted for the regular tests, and it was found that the actual values of the resistances in the ratio arms of the bridge could be changed by more than 100 per cent. without effect upon the balance; also, that the power-factors of the mica condenser and the air condenser were so nearly equal that no series or parallel resistance was necessary to cause silence in the high-resistance watch-case telephone receiver used as a detector.

The standard condenser was assumed to have zero power-factor, and its capacity was assumed to be independent of frequency. In Fig. 1, C is this standard condenser, c is the condenser being compared with C, the ratio arms of the bridge are represented by R and r, the compensating resistance by S, and the fictitious parallel resistance of the condenser being tested

[3] Grover, *Bull. Bureau Standards*, vol. 3, No. 3, 1910.

by s. When no current is passing through the detector, which is the condition of balance, the power-factor must be the same in both arms of the bridge, and the wave must have the same amplitude at each terminal of the detector D. From these conditions we have

$$c/C = R/r = S/s.$$

The fact that condensers take some current when impressed with a direct voltage, over and above the capacity charging cur-

FIG. 2a.

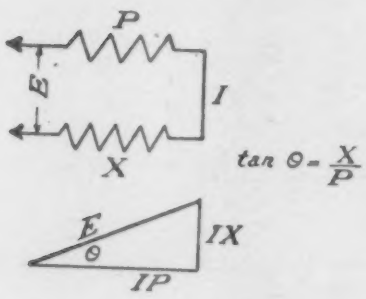
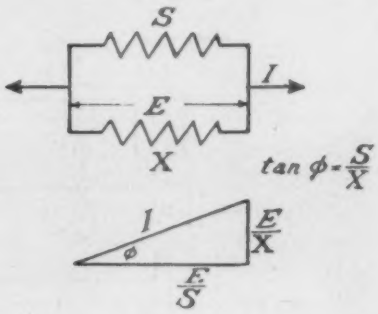


FIG. 2b.



rent, led the writer to adopt the convention that the fictitious resistance is a resistance in parallel with the capacity. If a series resistance is used in place of S to compensate the bridge for power-factor, it is reduced to the equivalent parallel value by the equations obtained from Figs. 2A and 2B. If the two circuits there represented are equivalent,

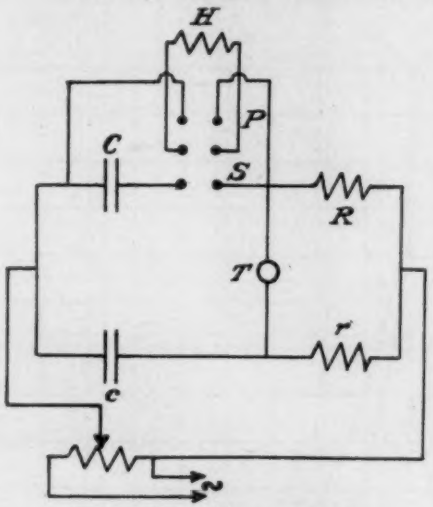
$$\tan\theta = \tan\phi, \text{ and } PS = X^2,$$

and the equivalent parallel resistance S can be calculated from the observed value of P. The actual bridge arms and the compensating resistances used were Leeds & Northrup dial type resistance boxes, and had the makers' guarantee of being accurate to better than 0.1 of 1 per cent.

The tests on all except the ice condenser were made at a temperature of 19° C. The condensers were kept in the test-room, which could be kept within 1 degree of this temperature by a thermostat. Condenser temperatures were read by mercury thermometers in intimate contact with the outer surface of the

condenser dielectric, and readings were recorded only when the thermometers had indicated the above temperature for some hours. The connections used are shown in Fig. 3, where R

FIG. 3.



Wien modified bridge arrangement.

and r are the bridge arms, C and c the capacities, p the fictitious parallel resistance of the condenser c, and H the compensating resistance. When series values of H were used, which was

TABLE I. MICA CONDENSER. CONDENSER NO. 13944 SET TO 0.5 μ. TEMPERATURE 19.0° C.

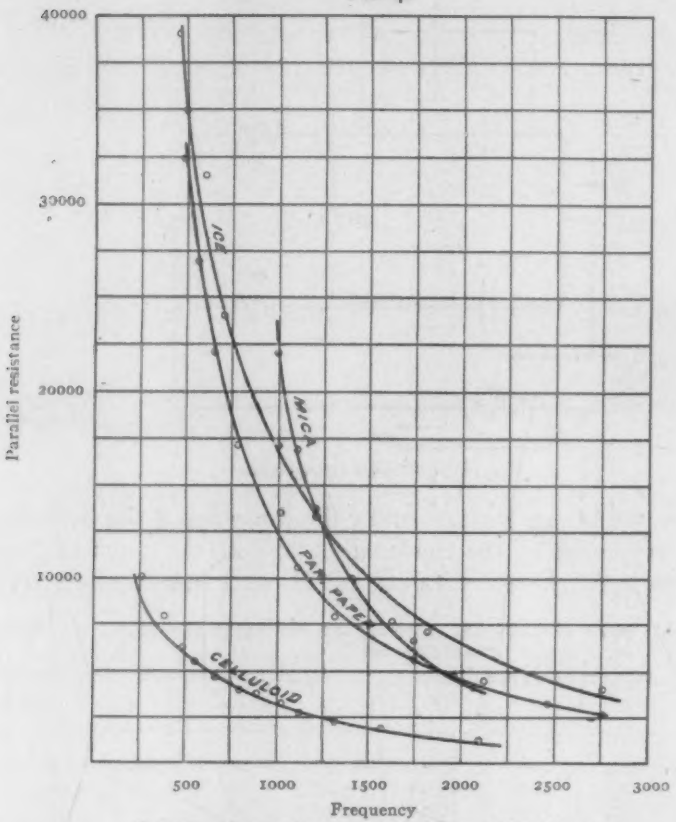
f.	R.	r.	S.	c.	s.	x	p/x
966	804	1000	17800	0.402	22100	410	53.9
1108	803	1000	13500	0.4015	16800	357	47.1
1206	803	1000	10700	0.4015	13310	328	40.6
1400	803	1000	7900	0.4015	9840	283	34.8
1726	803	1000	5200	0.4015	6480	229	28.3
2110	802	1000	3500	0.4010	4370	187	23.2
2748	801	1000	2100	0.4005	2620	144	18.2

accomplished by throwing the switch to S, the values of S which occur in the equations and in the appended sample table of readings and calculated values (Table I) are found from the corresponding series values by the equation $PS = X^2$. In Table

I, capitals refer to the standard condenser, small letters to the tested condenser.

To illustrate the method of recording data and calculating the constants of the condensers, the results obtained from the tests on the mica condenser are given in Table I. These results,

FIG. 4.



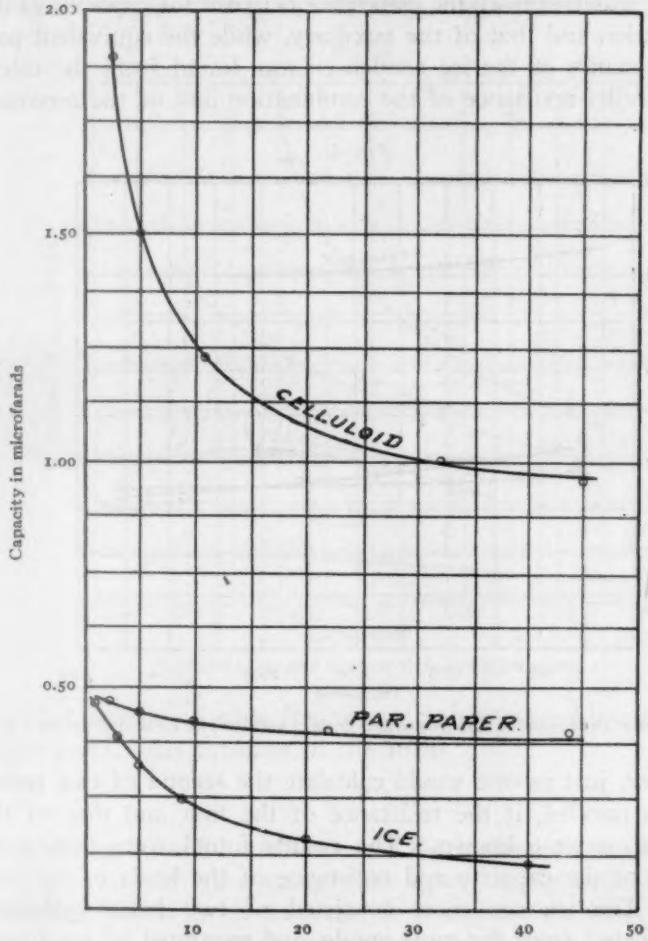
Variation of equivalent parallel resistance with frequency.

together with those of the capacity and power-factor tests on the other condensers, are plotted in Figs. 4, 5, 6, and 7. In the tests on ice, the capacity of c was much smaller than in the other tests, and the symmetry of the bridge was destroyed by the necessary employment of a long pair of air-insulated leads carried to the refrigerating room. The above method was there-

fore abandoned, and the tests were made by the following substitution method:

The condenser under test, and an auxiliary mica condenser,

FIG. 5.

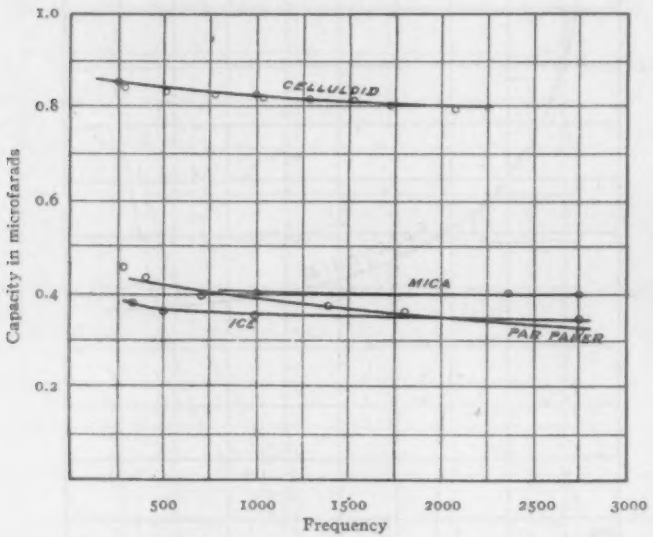


Variation of capacity with frequency.

were both placed at the end of the leads remote from the testing apparatus. The auxiliary mica condenser was first compared with the standard, and its capacity and fictitious parallel resistance calculated as indicated above. The ice condenser was then

connected in parallel with the auxiliary condenser, and the combined condensers were compared with the standard, and the capacity and power-factor of the combination were similarly calculated from the results of this test. The ice condenser capacity was therefore the difference between the capacity of the combination and that of the auxiliary, while the equivalent parallel resistance of the ice condenser was found from the calculated parallel resistance of the combination and of the auxiliary

FIG. 6.



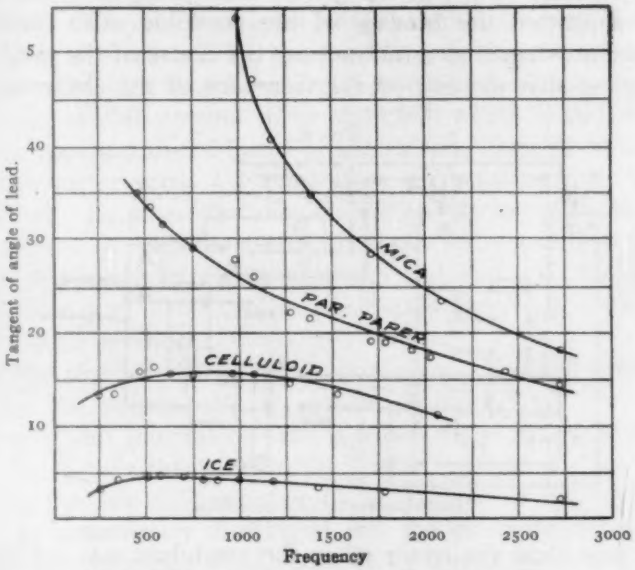
Variation of capacity with frequency. Scale of ordinates for ice is microfarads × 10^{-1}.

condenser, just as one would calculate the second of two resistances in parallel, if the resistance of the first and that of the combination were known. The results found were thus independent of the capacity and resistance of the leads to the cold room. The ice condenser consisted of two brass cylinders, copper-plated from the same anode, and separated by ice frozen from water triply distilled. The dimensions of the cylinder of dielectric, when frozen, were: length, 42.0 cm. (16.55 inches); mean radius, 10.0 cm. (3.94 inches); thickness of dielectric, 0.30 cm. (0.18 inch). The water was frozen gradually from the bottom upward. Connections were made between the en-

closing metal cylinders and the testing bridge by a pair of bare copper wires. These passed through glass tubes where they pierced the walls of the building, and were suspended at but four other points.

The curves of Fig. 4, showing the variation of fictitious

FIG. 7.



Variation of tangent of angle of lead with frequency.

parallel resistance with frequency, closely resemble rectangular hyperbolas. An equation of the form

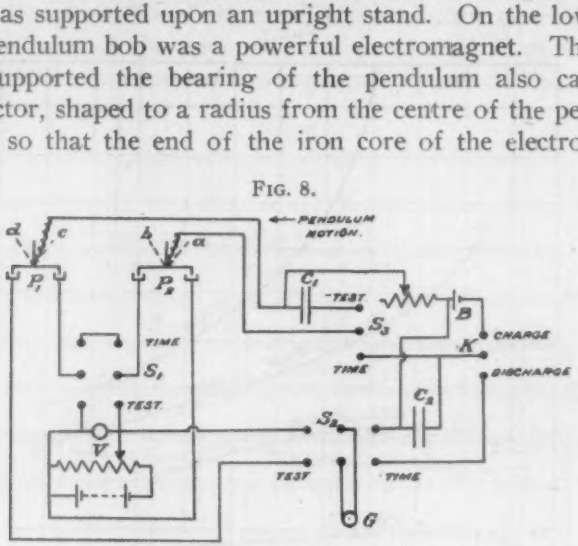
$$(f + a)(p + b) = k,$$

in which a, b, and k are constants determined from the curves, will give in each case values that agree closely with the corresponding points on the curves. It is improbable, however, that the relation is as simple as is indicated by this equation. It would be interesting to make further tests over an extended range of frequency; it seems probable that the equations calculated from the short range of frequency given in Fig. 4 would no longer hold.

To find the capacity of these condensers on times of charge

equivalent to frequencies lower than the lowest afforded by the Vreeland oscillator, a magnetically operated ballistic pendulum was used. This was constructed as follows: To the lower end of a long steel rod was attached a heavy bob of lead. This swung as a pendulum, and was provided with a polished pin bearing, which was supported upon an upright stand. On the lower end of the pendulum bob was a powerful electromagnet. The stand which supported the bearing of the pendulum also carried a brass sector, shaped to a radius from the centre of the pendulum bearing, so that the end of the iron core of the electromagnet

FIG. 8.



Connections for ballistic pendulum.

would just clear the sector when the pendulum was set swinging. On the sector were mounted two single-pole, double-throw switches, which made contact, when thrown from one side to the other, in mercury cups by means of fine platinum wires. Each switch carried a light armature of soft iron, and the pendulum, on passing this armature, would throw it over, thus effecting the desired circuit changes. The connections employed are given in Fig. 8. In this figure, P_1 and P_2 are the switches operated by the pendulum. The motion of the armatures is arrested, as soon as contact is made, by a steel screw in the armature coming against the metal of the mercury cup. The armatures were carefully adjusted to be free from any tendency to fly back after the pendulum had passed.

In testing a condenser for capacity, by this apparatus, the switches P_1, P_2 are thrown into the positions "a, c," and the circuit switches S_1, S_2, S_3 are thrown into the "test" position.

The condenser C_1 is thus short-circuited. The pendulum is then released with its electromagnet "on," and swings from right to left, throwing switch P_2 to "b" position, which charges the condenser C_1 to the potential V. An instant later switch P_1 is thrown by the pendulum to position "d," which disconnects the condenser C_1 from the voltage and connects it to the galvanometer G, causing it to give a ballistic deflection, which is read. The electromagnet current is interrupted before the switches are reached by the pendulum in its return swing, in order to be sure that the charge has not lasted long enough for any appreciable amount to be absorbed, which would be shown by an apparent shift of zero of the galvanometer indicator. The galvanometer used, a Nalder Bros. D'Arsonval, was critically damped. Its proportionality on ballistic throws was tested over the range of deflection used in these tests, and was constant over this range to within 0.25 of 1 per cent. Its ballistic constant was 5.77×10^{-9} coulombs per scale division at a distance of 1000 scale divisions.

The time of charge of the condenser C_1 is the time during which the switches P_1, P_2 are in positions "c," "b," respectively. This interval of time is measured as follows: Switches S_1, S_2, S_3 are thrown into the "time" positions. By manipulating the key K, condenser C_2 is charged to the potential B, and is immediately discharged into the galvanometer G, giving a ballistic deflection D. Condenser C_2 is connected to the voltage B once more, then insulated; the pendulum is then released, and performs the same functions as in the "test" operation. This connects the resistance R across the condenser C_2 for the time during which switches P_1 and P_2 are in positions "c" and "b." The condenser is discharged into the galvanometer by manipulating key K, before the pendulum reaches the switches in its return stroke, and this new deflection, d, is read. This second deflection corresponds to the residual charge left in C_2 after its contact with the resistance R. Then the desired time is given by the expression,

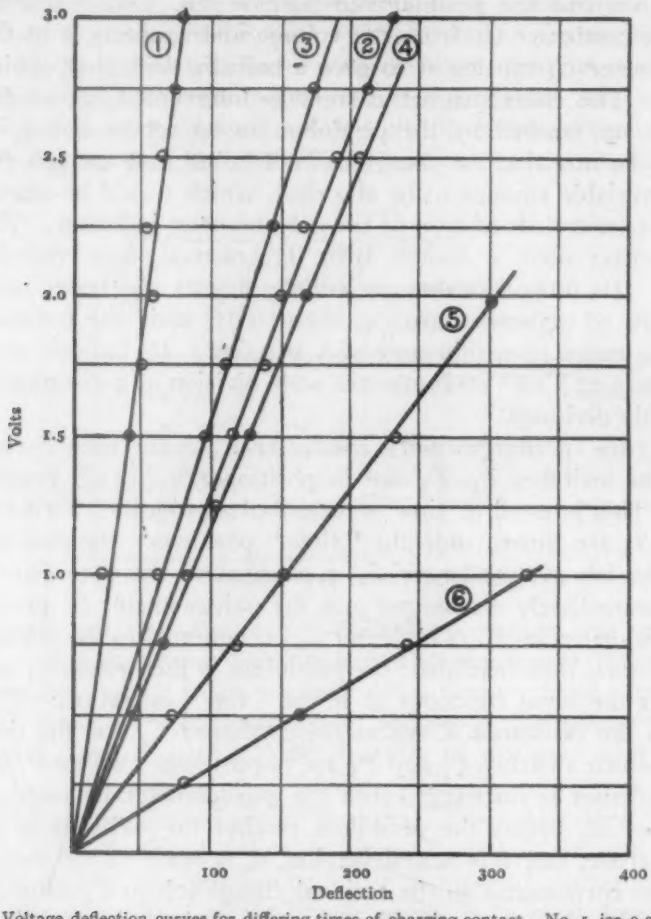
$$T = 2.3RC_2 \log_{10} D/d.$$

For the best precision in the measurement of the time T, the resistance R was made approximately equal to T/C_2.

The ballistic pendulum could not be relied upon to give con-

sistently times of charge larger than 0.30 second or smaller than 0.0060 second. Remembering that the charging current through a condenser in each direction, on the application of alter-

FIG. 9.



Voltage deflection curves for differing times of charging contact. No. 1, ice 0.025 second; 2, ice 0.35 second; 3, paper 0.008 second; 4, paper 0.19 second; 5, celluloid 0.011 second; 6, celluloid 0.19 second.

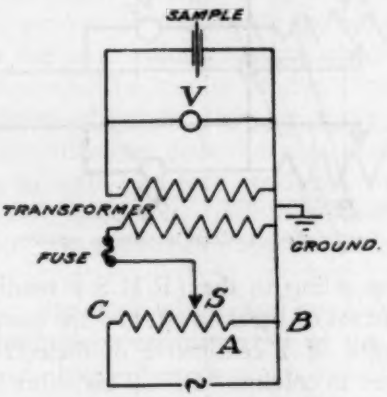
nating potential, continues through half a period, the frequency, f, is seen to correspond to a time of charge of $\frac{1}{2f}$ seconds. It has been found that constants calculated by this relation from direct-current tests on condensers agree closely with those observed

with equivalent frequencies of alternating current. The frequencies used in plotting the curves in Fig. 9 are found from the measured times of charge by this relation.

The direct-current resistances of these condensers were found by the "leakage" method, using the pendulum as a charge and discharge key. The values found were reduced to specific resistances, and appear in Table IV.

The breakdown tests were made upon portions of dielectric removed from the tested condensers. They were made as follows: The samples were inserted between highly polished discs

FIG. 10.

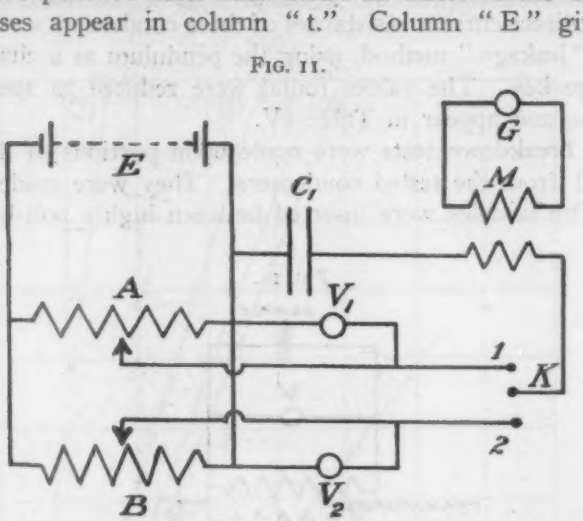


Connections for breakdown tests.

of brass, 2 cm. (0.4 inch) in diameter. The testing voltage was applied at a constant rate of about 600 volts per second. Fig. 10 gives the apparatus used, and the connections. The uniform gradient was secured by causing the slider S to move with uniform speed over the rheostat CAB. The speed had become constant by the time this slider reached A, having been started at B; and the portion BA of the rheostat was of negligible resistance. That from A to C was of such value that the transformer magnetizing current was about 1 per cent. of that taken by the rheostat, so that the voltage applied to the transformer, and hence that applied to the sample tested, was proportional to the distance AS. The breakdown voltage was read at the instant of breakdown on the electrostatic voltmeter V, which was

critically damped, and the speed of the slider S was the same as the free speed of the needle of the voltmeter V. The testing discs were polished after each test. In Table II the dielectric thicknesses appear in column "t." Column "E" gives the

FIG. 11.



Test for effect of voltage increase on capacity.

maximum corresponding to the (R.M.S.) reading of the voltmeter V at the instant of breakdown; and the quotient E/t, or the breakdown strength of 1 centimetre of dielectric between parallel faces, is given in column "P." This value holds only when

TABLE II. BREAKDOWN TESTS.

Dielectric.	t.	E.	P
Mica	0.004 cm.	4,240	1.060×10^7
Paraffined paper	0.018 cm.	12,700	0.707×10^6
Celluloid	0.005 cm.	5,230	1.045×10^6
	0.010 cm.	10,500	
Ice	0.260	2,828	
	0.460	4,240	0.0106×10^6
	0.400	4,670	

testing terminals are used by which the field is not intensified at the boundary between terminal and air. In the case of ice, plane parallel plates were used, which had been frozen at the same time and from the same supply of water as the dielectric in the cylindrical condenser.

The fact that the curves of Fig. 9 are all straight lines shows that the capacity of these condensers was independent of applied voltage over the range of voltage used in the tests. The apparatus and connections used to test this point for higher voltages are shown in Fig. 11. In making a test, slider A was moved until V_1 was zero, and switch K was thrown to position 1. Slider B was then moved until the voltmeter V_2 indicated a predetermined voltage which would cause a ballistic throw of G, just within the limits of its scale. K was then thrown to 2, the deflection noted, A was moved until $V_1 = 2V_2$, K was thrown back to position 1 and the new deflection noted, and so on up to the limit of the supply voltage E. The mutual induction coil M was used to get rid of the steady galvanometer deflection, proportional to the total voltage on the condenser, due to the condenser resistance. The results of these tests showed, when plotted in the form of curves, that the curve between voltage increment and galvanometer deflection was a straight line. The value of E was 90 volts, and each condenser was taken through a cycle of from zero to 90 volts, back to zero, down to minus 90, and back to zero. No evidence of any resulting closed loop was obtained.

The object of the work was to find any possible relation between the different electrical properties of the materials tested. To do this, the results are best shown as values per unit volume of dielectric, since the specific inductive capacities and the specific gravities are quite different. Table IV exhibits the final results of the work; and in order to make this table as clear as possible, the following explanation is given of the quantities tabulated, and their derivation.

Dielectric Constant, or Specific Inductive Capacity:

This was obtained by dividing the measured capacity of each condenser by the capacity of an air condenser of the same number of conducting sheets, the same average area per sheet, and an air separation equal to the thickness of dielectric in the condenser tested. If A is the product of the number of sheets by the average area per sheet, and t is the average thickness of one dielectric sheet, the capacity of the equivalent air condenser will be

$$g = \text{air capacity} = 10^{-13} A/(1.132t) \text{ farads.}$$

The ice condenser had been used in some previous work,[4] and its air capacity had been directly measured. Table III shows the equivalent calculated air capacities for the four condensers tested. In Table IV the specific inductive capacity is the quotient of the measured capacity by the corresponding value of g from Table III.

TABLE III. CAPACITIES OF EQUIVALENT AIR CONDENSERS.

Condenser.	Air capacity, g. farads	
Mica	10.050	10^{-4}
Paraffined paper	7.170	10^{-6}
Celluloid	6.180	10^{-4}
Ice	4.410	10^{-10}

Maximum Breakdown Voltage per Centimetre. (See Table II.)

Maximum Absorbable Energy, Watt-seconds per Centimetre Cube:

The energy required to charge a condenser c to a potential difference E is

$$Q = 0.5\, cE^2.$$

If the breakdown voltage per centimetre is represented by $P = E/t$, and if the condenser volume is $V = At$, where A is the total effective conducting area of one terminal, and t is the average dielectric thickness per sheet; and if K is the dielectric constant of the material, the condenser capacity will be

$$c = 10^{-13} AK/(1.132t),$$

provided that end effects may be neglected. Then the maximum amount of energy that unit volume of the dielectric can be made to absorb—regardless of the capacity which this volume of the dielectric is made to give—will be

$$W = 4.42 \times 10^{-14} KP^2.$$

The limiting condition is that if a voltage be applied in excess of P, the condenser will break down.

90° Minus Angle of Lead:

The tangent of the angle of lead for a condenser is R/X, where R is the equivalent parallel resistance, and $X = \frac{1}{2}\pi fc$. The angle is calculated from the values of R, f, and c.

[4] Thomas, *Phys. Rev.*, vol. 31, No. 3, 1910.

Equivalent Parallel Resistance, Ohms per Centimetre Cube:

If the measured parallel resistance is R, the value per centimetre cube will be RA/t.

Conductivity per Centimetre Cube:

Reciprocal of equivalent parallel resistance.

Per Cent. Change in Capacity per Cycle:

If the capacity at frequency f is C, the per cent. change in capacity per cycle will be

$$100dC/Cdf,$$

where dC and df are small corresponding changes in capacity and frequency.

Per Cent. Change in Equivalent Parallel Resistance per Cycle:

This is calculated from the curves, exactly as is the percentage change in capacity per cycle from the capacity curves.

Direct-Current Conductivity per Centimetre Cube:

If D is the measured direct-current resistance of the condenser, the conductivity per centimetre cube will be

$$(DA/t)^{-1}.$$

It will be noted that in reducing the results to values for unit dielectric volume, the following assumptions were made:

(1) That the breakdown strength of the material varies directly as the thickness between terminals.

(2) That the power-factor, other things being equal, is independent of the value of the condenser capacity.

(3) That the conducting area is very large compared to the thickness of each dielectric sheet.

In calculating the values which appear in Table IV, values for frequencies of 1000 and 15 cycles per second were deduced, as these are approximately the limits of commercial frequencies. The values given in Table IV show that there is a very evident general relation between the electrical properties of the four materials tested. As the dielectric is changed, from mica through paraffined paper and celluloid to ice, it is shown that the dielectric constants increase very greatly. At the same time, the breakdown strength becomes smaller, the resistance offered to the passage of both direct and alternating current grows less, the maximum energy that can be absorbed by a condenser of given dimensions diminishes, and the rate of change of capacity

with frequency increases; also, the alternating-current resistance of the material changes more and more slowly with frequency, which shows that a progressively larger percentage of the conductivity of the material is independent of frequency,—*i.e.*, is a true "conductivity," and is not radically different on direct-current and alternating-current circuits. It may be said here that the results found for mica are not necessarily valid, since

TABLE IV. RESULTS OF TESTS, AT UNIT AREA AND UNIT THICKNESS OF DIELECTRIC.

At 1000 cycles.	Mica.	Paper.	Celluloid.	Ice.
Maximum breakdown volts per centimetre....	$1.06\ 10^{6}$	$0.71\ 10^{6}$	$1.05\ 10^{6}$	$0.011\ 10^{6}$
Specific inductive capacity	4.00	4.90	13.26	86.40
Maximum absorbable energy, $\frac{\text{watt—seconds}}{\text{cm. cube}}$	0.198	0.108	0.640	0.00040
90°—angle of lead	$0°–57'$	$2–°10'$	$3–40'$	$13°–39'$
Equivalent resistance, $\frac{\text{ohms}}{\text{cm. cube}}$	$2.56\ 10^{10}$	$1.02\ 10^{10}$	$0.207\ 10^{10}$	$7.22\ 10^{7}$
Conductivity per centimetre cube.....	$3.91\ 10^{-11}$	$9.84\ 10^{-11}$	$48.3\ 10^{-11}$	$1400\ 10^{-11}$
Per cent. change in capacity per cycle.....	$2.18\ 10^{-4}$	$14.31\ 0^{-4}$	$30.7\ 10^{-4}$	$70.0\ 10^{-4}$
Per cent. change in resistance per cycle.....	0.258	0.146	0.106	0.127
At 15 cycles.				
Specific inductive capacity	4.09	5.77	18.60	429.0
Maximum absorbable energy, $\frac{\text{watt—seconds}}{\text{cm. cube}}$	0.203	0.126	0.90	0.002
Per cent. change in capacity per cycle.....	0.00	0.306	1.74	1.59
On direct current.				
Conductivity per centimetre cube.....	$2.42\ 10^{-17}$	$2.27\ 10^{-11}$	$7.15\ 10^{-12}$	$1.63\ 10^{-9}$

the only apparent difference between the standard and the tested condensers was in the method of manufacture. The diversity between the values found for mica and for paraffined paper, however, is far too great to be accounted for by differences in method of manufacture—and this is even more true in the case of the celluloid and ice condensers.

Grover (*l. c.*) has shown that the best possible single test on mica condensers is the power-factor test. It is evident from

these results that in many cases the suitability of a given material for use as a condenser dielectric may be judged without recourse to a measurement of specific inductive capacity. The material covered in these tests, however, is not sufficient to warrant the conclusion that the relations indicated are of general application. An extension of these tests to liquid dielectrics would undoubtedly throw more light upon the point in question.

SUMMARY.

This paper describes and gives the results of tests upon the electrical properties of mica, paraffined paper, celluloid, and ice. The materials were tested in the form of condensers, and the tests included measurements of the capacity, power-factor, conductivity, breakdown strength, and capacity variation with applied voltage. The tests covered a range of from 3000 cycles to 250 cycles per second by sine-form alternating voltage, and from 83 cycles to 1 cycle per second by unidirectional charges applied for equivalent times of charge. The results of the tests were reduced to values for unit dielectric volume, and a table of such results is included. It is shown that there is a general relation between the electrical properties of the materials tested,—*i.e.*, that the substances with high dielectric constant have also high dielectric losses, low breakdown strength, and low insulation resistance. Temperature effects were eliminated by making all measurements on each condenser at a constant temperature. As far as possible, this temperature was made the same for different materials, so that a comparison of the results is not subject to temperature correction. It is shown that within ordinary commercial limits the capacity of condensers having either of these substances as dielectrics is independent of the magnitude of the voltage applied to them. The results of the tests are given in the form of curves.

In conclusion, the writer wishes to express his sincere thanks to Professors W. F. Magie and E. F. Northrup, of Princeton University, for their unfailing interest and invaluable assistance during the course of the work.

PALMER PHYSICAL LABORATORY,
Princeton University,
June, 1912.

Photography of Particles Ejected from Atoms. C. T. R. WILSON. (*Engineering*, xcv, 362.)—By the aid of Röntgen rays electrons may be ejected from ordinary atoms. Indirect methods are usually used in the study of electrons. Electrons, when ejected, left trails behind them, and these have been photographed. Each electron ejected traversed a large number of gas atoms. But on modern theories each such atom is a miniature solar system, the planets being represented by electrons, which are held together by electrical instead of gravitational forces. When a disturbance of sufficient violence was set up, an electron might escape from one system and might become attached to another system. Now molecules of gases or vapors would more readily attach themselves to charged ions than to uncharged atoms, and every ion could be made a centre of condensation in supersaturated water vapor. By the aid of the *cloud-chamber* the ions can be caught in the positions they occupy when just set free. The trail of a particle, invisible in itself, is thus marked by a crowded line of clouds, and individual ions could be distinguished under certain conditions. Nine photographs taken in this way are given in the paper, and three diagrams explanatory of the experimental methods adopted.

Photoelectric Behavior of Iron in Active and Passive State. H. S. ALLEN. (*Roy. Soc. Proc., Ser. A*, lxxxviii, 70.)—It is well known that ordinary iron which is acted on energetically by dilute nitric acid can be made to assume a passive condition by immersion in strong nitric acid or by other powerful oxidizing agents. The author has compared the photoelectric activity of iron in the active state with that of the same sample in the passive state, dry iron plates being used in each case. The photoelectric activity measured was that due to the light from a mercury lamp. The experiments prove that iron which is chemically active is active in the photoelectric sense, while iron which is passive shows much less photoelectric activity—in some cases none that can be detected. This result is considered in good agreement with the theory which attributes passivity to the condition of the gaseous layer at the surface of the metal.

Electric Locomotive for the New York Central Railway. ANON. (*Elect. World*, lxi, 797.)—In this article is given a detailed description of an electric locomotive, constructed by the General Electric Company. It has eight motors with a continuous, tractive effort of 10,000 pounds at 60 miles per hour. This locomotive weighs 100 tons, as compared with 115 tons, the weight of those already in use. It is more powerful than these, and is provided with forced air ventilation with a view to continuous high-speed service.

THE RELATION OF MATTER TO ELECTRICITY.*

BY

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Member of the Institute.

In my address this evening I am prepared to outline in simple language the present attitude of science toward electricity and its relation to matter. It will, of course, be quite impossible in the time at my disposal to give the lines of reasoning or the methods of investigation which have led up to the present-day conclusions very generally accepted. Those wishing to study the subject more in detail, I must refer to the original papers of the several experimenters to be hereafter mentioned, whose work furnishes strong evidence in favor of the views here to be set forth.

My discourse will not be ultra-scientific, but I shall try to give the layman an intelligent notion of what science has done and is doing in this special line of investigation.

We live in a wonderful age—not only relatively but absolutely, and I refer not only to the marvelous progress in pure science, but to the most impressive results due to the successful applications of the principles of pure science to the production of useful appliances. Within my own recollection have appeared the invention of the telephone and its adoption by the whole civilized world—the application of electricity to not only local motive power, but also to that of moving vehicles of all kinds, even the most powerful locomotives for drawing the fastest passenger trains—the internal explosive engine used on a large percentage of the automobiles now made—the useful development of the electromagnetic theory of light from the mathematics of Maxwell through the experimental demonstration of Hertz to the application by Marconi and others for the purpose of signalling at a distance without the use of any conducting wires. These and many other things could easily be enumerated to

* Presented at the meeting of the Section of Physics and Chemistry, held Thursday, March 6, 1913.

illustrate the wonderful progress of physical science and its applications during the last twenty-five years, and to treat any single one in any detail would require volumes rather than the few pages devoted to the present discourse.

As the recent progress of the science of electricity and its industrial applications has perhaps been the most remarkable and contributed most to the welfare of mankind, it is quite fitting that we should consider briefly the nature of the agent which is directly or indirectly responsible for the effects produced, and determine if possible what relation it bears to the other agencies or entities with the nature of which we feel more familiar.

Not so very long ago teachers of physics used boldly to assert that matter and energy comprise every conceivable existence in the physical world. Electricity and the ether, however, presented difficulties to this brief classification, though it was often predicted that at some time and somehow electricity would be shown to be a connecting link between ether and matter. Although this expectation has not been up to the present time realized, the accepted belief as to the relation of electricity to matter will be apparent when we have taken a brief survey of the evidence about to be presented.

Since I have referred to the ether it seems fitting that a brief comment should be made in regard to it. As the wave theory of light more than a hundred years ago gained ground against the corpuscular theory long held by Newton and his followers, it became necessary to postulate a medium in which the waves could be propagated. The necessary properties of such a medium to account for the special kind of wave and their high speed were listed and described. The belief in the existence of some sort of medium seemed imperative. For example, heat and light are present in the sun; 8 minutes later they are received by the earth; during that 8 minutes where are they and what are they? "Radiant energy in the ether," has been the universally accepted answer till quite recently, and the postulate of the ether has been one of the fundamentals of physics. Even up to 1904, at the Congress of Arts and Science at St. Louis, physics was discussed under three heads, as "physics of matter," "physics of the ether," and "physics of the electron." Even at the present time, I believe that the great English physicist, Sir Oliver Lodge,

contends that the ether has a very definite and concrete reality. On the other hand, within the last few years there has been developed a new branch of philosophical physics, known as "The Principle of Relativity," enunciated by Einstein of Berne and mathematically studied by Minkowski. In America the chief writers have been Lewis, Comstock, and Tolman.

The theory of relativity is an attempt to furnish a logical explanation of two experiments on the velocity of light, the results of which at first seem contradictory. We have not time to consider these experiments, but one of them was by Fizeau, in 1851, which seemed to show that the properties of the ether through which light passes are in no way affected by the motion of a gas present; *i.e.*, the ether stays at rest. If this be so, the velocity of light should be different, depending on the direction of the observer with reference to the light source. Michelson and Morley tried this test with the greatest care, using methods sure to detect a difference if it existed. None was found. In other words, the ether has not been proved to be at rest relatively to moving matter, and the relativists are inclined to conclude from this that no such medium as the ether really exists and that we are just as ignorant of the mechanism of the transmission of radiation as we are of that of gravitation. So physics along these lines may be on the verge of another revolution, though the speaker is inclined for the present to retain his mental conception of an elastic ether and its electromagnetic waves.

The objectivity of matter, I presume, is apparent to all of us, Tait calling attention to the fact that it is often offered "for sale" or "for let," and, of course, anything that can be bought or hired must have an objective existence. But surely accepting such an argument would imply far too much now in America. Indeed, the same author admits later that "to have its price" is not conclusive of objectivity, citing as evidence that titles, family secrets, and even college degrees are sometimes sold.

On first thought it would seem far easier to study matter than to study energy, and this is so, perhaps, if one does not proceed farther than to analyze and to classify the properties of the bodies having tangible and visible size. We can, for example, find out nearly all there is to know about a certain piece of glass, considered only as a mass of glass of definite size and shape.

We can measure its mass correct to one part in ten million; its linear dimensions correct to one-hundred-thousandth of a centimetre; its density, elasticity, refractive index, dispersive power, etc., are known to a high degree of accuracy. Suppose now we have made a similar physical examination of a definite piece of quartz; at once is suggested, why this difference in properties? They must be due to the differences in the finer structure of the substances not apparent by the grosser methods of examination. Chemistry now steps in with its beautiful analytic methods and classifies the many substances or kinds of matter composing bodies.

At any particular time in the history of science a chemist would have told us that all substances are either elementary or compound, the number of the former class being definite, say seventy-five, while the number of compounds is far greater and less definite. At almost any subsequent date the number of elements would be stated as larger, this increase from time to time resulting in the dividing of a supposed element into two, or, from the discovery of new ones, all the former ones remaining intact. The separation of didymium a few years ago into its neo- and praseo- constituents is an example of the former method, while the latter has been exemplified more recently by the discovery of several unsuspected constituents of the atmosphere—I refer to the inert gases of the argon group.

Until rather recent years physics was said to treat of masses and of molecules and their energy relations, while chemistry investigated molecules and atoms and their energy relations. More recently physics and chemistry together, aided by that ever-powerful ally, mathematics, have strenuously attacked the atom, hoping through this doorway—narrow, it is true, but manifold—to flash now and then a ray of light illuminating for a moment, if but dimly, the mysteries beyond.

I have used the terms molecule and atom. Let us note clearly what these signify. The former, which from its derivation means "a little mass," is defined as the smallest portion of any particular substance or kind of matter which can exhibit the properties of that substance. For example, the smallest particle of common salt that is salt is the molecule; if by any means, as in chemistry, we subdivide the molecule, we get atoms,

alike or different, and these present properties entirely different from those of the molecule. In the case cited a molecule of salt is built up of an atom of the metal sodium and an atom of the gas chlorine—two substances quite unlike and each entirely different from salt. These are called elements. The suggestion of an atomic theory of matter is over two thousand years old, but the real founder of the scientific modern kinetic theory was the English chemist Dalton, and during the last century it has been established upon a most firm foundation.

Suppose we consider for a moment the size of these atoms of which we so confidently speak. Chemistry furnishes us with indisputable evidence as to their *relative* sizes; we know that an oxygen atom is about sixteen times as massive as one of hydrogen, which is the smallest known; but what about actual size? I cannot give you the methods of attacking this problem; many there are, but I can briefly state the results.

In describing magnitudes of quite different orders we are forced to adopt appropriate units for expression that the mind may, in a measure at least, be able to appreciate the different magnitudes expressed. The mention of a mile calls to one's mind a rather definite length which it appreciates, so when one is told that two places are twenty-five miles apart we know about what that means. If, however, this distance were expressed in feet or in inches, no one would have any idea of the magnitude expressed, because of the inappropriateness of the small unit to express so large a distance. Again, we receive very definite information when told that two stakes are placed ten feet apart, while if this distance were expressed in miles we should again be hopelessly confused.

Now a molecule is so small at to require an exceedingly small unit to express its size. Microscopes with their micrometre eyepieces can measure distances smaller than a one-hundred-thousandth part of an inch, or about one-half the wave-length of yellow light. But this distance is one thousand times greater than the probable diameter of a hydrogen atom. A better idea is gained in this way than if I had said at first that the diameter of a hydrogen atom is about a hundred-millionth of an inch. Again, as you all know, nearly all scientific measurements are made in the metric system, in which a metre (about 40 inches)

is the starting point. A thousandth of this is a millimetre (about 1/25 inch), and a thousandth of this is called a micron, and 4000 hydrogen atoms laid side by side would reach about this distance. Further, it is estimated that the number of atoms in a single drop of water would be expressed by a number far beyond one's mental power to appreciate—a number requiring twenty-two or more figures to write.

Again, the kinetic theory of matter now universally accepted teaches us that these atoms and molecules are in a state of ceaseless motion, the energy of which constitutes heat. The conditions are simplest and best understood in the case of a gas such as the air. If we imagine air magnified about a thousand million times, to use an illustration of Millikan's,—*i.e.*, to make a pea grow to the size of the earth,—a molecule would be about as large as a football, and if we could get an instantaneous snap-view of the situation the scattered state of these bodies would be represented by one football in each ten-foot cube. Furthermore, the state of motion would be such that on the average each would travel about 300 feet before hitting a fellow. Furthermore, in the case of hydrogen, the molecular speeds are of the order of magnitude of a mile a second.

The advances in physical science during the last century have been many and rapid, yet made with such care, each new discovery or generalization being criticised so severely and impartially, that what has stood all tests and finally been generally accepted forms a most stable and reliant structure, to which, very recently, the trial framework of another story has been erected.

From the various experiments described by Crookes in 1879 he was led to believe that the residual gas in a very highly exhausted glass bulb when subjected to the action of an electric discharge from an ordinary induction coil presents properties so different from those of ordinary gas as to warrant the use of the term "radiant matter" to what we now call the cathode rays, and a more appropriate term cannot be conceived of in view of later researches. Crookes himself believed these to consist of streams of negatively electrified molecules projected with high speed from the cathode, and he constructed a number of ingenious mechanical devices in support of this view. Al-

though Crookes's conclusions were not then accepted by all, later developments have shown them to be in the main correct, except as to the size of the particles concerned.

It had been shown by Crookes that the cathode stream is easily deviated, both by a magnetic field and by an electrical one, and so by an ingenious though simple line of reasoning, based upon well-known principles of dynamics, J. J. Thomson was able to determine the speed, the mass, and the electric charge of these little bodies. It was found further that the results were quite independent of the residual gas in the tube and also of the material of the electrodes. As we proceed this will be seen to be very significant.

The reasoning and the mathematics, though simple, would be out of place in an address of this character, and I must ask you to accept the results. In Thomson's experiments the values obtained for v, the speed of the particles, was between 2.2 and 3.6 times 10^9 cm. per second, or about one-tenth that of light, the latter being 3×10^{10} cm. per second.

The value of e/m or of the ratio of the electric charge to the mass of its carrier was found to be between 1.5 and 2.0×10^7, each being measured in c.g.s. units. It was further found that this value also is quite independent of the kind of gas filling the tube before exhaustion, and also of the substance composing the electrodes. Thus one is forced to the conclusion that these little carriers, or "corpuscles," as Thomson called them, must be quite a strange form of matter and not at all identical with either a molecule or an atom, though perhaps forming a part, always the same in character, of atoms of all kinds.

Now it has further been shown that the value of e, or the charge conveyed by each carrier, is the same as that carried by a hydrogen atom in liquid electrolysis and therefore since about 10^{-4} of a gramme of hydrogen carries a unit charge, it follows that each corpuscle must have a mass equal to from one-fifteen-hundredth to one-two-thousandth of that of a hydrogen atom. In other words, the atom of the chemist and of the physicist, conceived of more than two thousand years ago by Democritus, and glorified, as Tait puts it, in that grand poem of Lucretius; of the chemist as the smallest portion of matter capable of forming part of a compound substance, of the physicist as the smallest

part that can receive or give an impulse or take part in an energy change, has been shown in the last few years to be about 1760 times more massive than the little body under discussion, and this even though we choose the least atom known, that of hydrogen.

In 1895 Röntgen discovered some very wonderful radiant effects from a Crookes tube, called by him the X-rays, the properties of which have been studied ever since all over the world, and which have become of vital importance in several departments of science. They differ from cathode rays in not being deviable by either a magnetic or by an electrical field. They are unlike light rays in not being susceptible either of reflection, refraction, or polarization within the usual meanings of these terms.

About a year after the Röntgen rays were discovered other rays having some properties in common with them and with the cathode rays also were discovered by Becquerel to be given off by uranium and its compounds. The results of the study of these rays have led to the development of a new subject in physics—radioactivity. A radioactive substance like uranium or thorium and their compounds is one giving off rays material or other kinds capable of ionizing the air, *i.e.*, making it a conductor of electricity.

Suppose we have a gas between two metal plates attached each to a terminal of some electric generator so that one plate is, as we call it, electrified positively and the other negatively. Ordinarily a state of equilibrium is maintained, as the gas is a first-rate insulator and no current passes between the plates. If, however, a uranium or a thorium compound be placed between the plates, the gas at once becomes partially conducting,—*i.e.*, it is said to become ionized,—and a small current begins to flow, which can be measured by suitable devices. It is this ability to ionize a gas that makes it possible to study radioactivity. Except at very low pressures it is thought that an ion consists of a charged nucleus surrounded by an attached group of atoms. At very low pressure the negative ion is identical with a particle in the cathode stream of a Crookes tube. Conduction in the gas thus consists of the carrying of the negative charges by the ions to the positive plate and of the positive charges to the negative plate, thus tending to equalize the potentials. We have here then true electric convection.

In 1898 Mme. Curie, having taken up the study of the various salts of uranium and then of the various minerals containing uranium, announced through Professor Becquerel her results. Her first important conclusions were that the salts were active in proportion to the uranium in them, but that the minerals were not so. For example, uraninite, or pitchblende, as it is called, was found to be several times as active as metallic uranium itself, hence uranium cannot be the chief agent in the production of the effects in the case of the ore.

After a long and most careful chemical research Mme. Curie and her husband separated from a very large amount of uraninite a very small quantity of an active substance similar to bismuth which seemed to be a new element. They called this polonium, from Poland, their native country.

Continuing their work with vigor, the Curies soon announced the separation of still another elementary substance from uraninite closely allied to barium with a radioactivity many thousand times that of metallic uranium. This they called radium. The great popular as well as scientific interest in this wonderful substance would justify the time necessary to relate some of its properties, even if it did not furnish a very suitable example for illustrating the latest theory of matter, to be spoken of presently. The quantity of radium obtainable from uraninite, so far the most fruitful source, is exceedingly small. It is estimated that to obtain a single pound, and that far from pure, would require the working up of 2000 tons of the mineral.

A third radioactive substance, which is allied to iron, was discovered by Debierne in 1899; this he called actinium. These events opened up an entirely new department of science, and the superb research work of the Curies, J. J. Thomson, Rutherford, Kaufman, Boltwood, Millikan, and many others probably whose names should with equal justice be mentioned, has resulted in much new science and in throwing some light on the mysterious problems yet to be solved.

Without going into the details of the methods of investigation, let me say briefly that it has been found that radium, for example, sends out so-called " rays " of three kinds. Rutherford designated them, first the α-rays, which were found to be positively electrified particles penetrating ordinary matter but feebly,

only very slightly deviable in the strongest force fields, and having a mass of the same order of magnitude as that of hydrogen atoms; second, the β-rays, identical with the Crookes or cathode rays,—*i.e.*, negatively charged particles, very penetrating, easily deflected by both a magnetic field and an electrical one, called at first "corpuscles," but later identified with electrons or the ultimate building material of atoms; and, lastly, γ-rays, probably identical with the Röntgen rays, very penetrating and non-deviable. A detailed study of radioactive phenomena shows with little doubt that the process is absolutely unaffected by any physical or chemical treatment. The activity is unchanged in passing from the temperature of liquid air to that of red heat. The activity of a radium compound is in direct proportion to the amount of uranium present, and is in no way dependent on the other substances in chemical composition. It would seem, therefore, that the changes going on are associated only with the atom of the active substance and not at all with the molecule of which that atom is a part. Since, too, it is only a substance of the greatest atomic mass, as for example uranium and thorium, which is radioactive, it is clear that the expulsion of a few α-particles would be quite possible without changing very much the total mass of the atom. For example, uranium changes its atom by the expulsion of two α-particles to a new and different atom discovered by Boltwood and named by him ionium, while ionium changes to radium by the loss of another α-particle. The proportion of the total atoms present at any time which expel α-particle each second differs with the different substances. For instance, the substance into which radium changes is a radioactive gas first known as radium emanation and later called niton; of this substance about two-millionths of the total number of atoms present at any time change per second. The result of this is that a given amount of niton is half changed in about 3.75 days. This is a rather rapid change, radium being reduced to half value in about two thousand years and uranium in 4.6×10^9 years. The view that the atoms of the radio-elements are undergoing spontaneous disintegration was put forward by Rutherford and Soddy as a result of evidence of the character cited above. On this view it seems probable that the escaping α- and β-particles are not set suddenly in motion, but that they

escape from an atomic system in which they were already in rapid oscillatory or orbital motion. The energy is then not communicated to the projected particles, but exists beforehand in the atoms from which they escape.

We have spoken of the β-particles as the electrons, but what about the α-particles? It was early shown that these are identical from whatever source derived, and, further, that *helium* is always associated with the minerals containing radioactive substances. This suggests that it has some necessary connection with the radioactive process. *Helium* has a peculiarly interesting scientific history. It will be recalled that in the early study of the spectrum of the sun a prominent line in the yellow close to the sodium lines was noticed by Lockyer which could not be identified as caused by any substance known then on the earth. The substance in the sun giving rise to this line was appropriately named helium. More recently, in 1895, Ramsay discovered helium occluded in certain minerals, notably cleveite, which were soon found to be radioactive. A little later Ramsay and Soddy obtained the helium spectrum from the gas emitted from a few milligrammes of pure radium bromide dissolved in water. The crucial test, proving beyond a reasonable doubt that α-particles without their positive charges constitute the helium atoms, was made by Rutherford by direct experiment, and Rutherford and Boltwood have made the latest and the most complete series of experiments for the direct determination of the amount of helium produced from a given quantity of radium under given conditions. Helium is further noted in being the most difficult and hence the last gas to be liquefied. This difficult feat was at last accomplished by Onnes of Leyden. At atmospheric pressure helium liquefies at 4.26° absolute; its critical temperature is 5.25° absolute and its critical pressure 2.26 atmospheres. When boiled at reduced pressure a temperature of about 1.5° absolute results, the lowest yet obtained.

Let us now return to the β-particles which have been shown to be identical with the cathode rays in a Crookes tube, except that when emitted from radio-atoms their speed is much greater, sometimes reaching nine-tenths that of light.

Since an electrically-charged body exerts force all around itself, it can be shown from theoretical considerations that to

start or stop or to accelerate such a mass requires a greater force than when not charged; this means that the body's inertia, or effective mass, is greater when charged. This is clearly due to the effect of the magnetic field always present when electricity is in motion.

In symbols, if the simple dynamic mass energy is $\frac{1}{2}mv^2$, m being the mass and v the speed, it has been shown by J. J. Thomson and others that this extra work required to produce the magnetic field is

$$\frac{1}{3}\frac{e^2}{a}v^2$$

where e is the electric charge and a the radius of the charged sphere.

Adding the magnetic energy thus developed in the ether to the mass energy, the total becomes,

$$E = \frac{1}{2}\left(m + \frac{2}{3}\frac{e^2}{a}\right)v^2$$

in which the quantity in parentheses becomes the effective mass or the real inertia of the combination, and

$$\frac{2}{3}\frac{e^2}{a}$$ the electric inertia.

Now let us take quite another attitude and adopt Faraday's conception of tubes of force and endow these tubes with momentum. Assuming again the same conditions, we can prove mathematically that the electric momentum due to the moving charge e—would be

$$\frac{2}{3}\frac{e^2}{a}v,$$

which gives the same value as before for the electric inertia, viz., $$\frac{2}{3}\frac{e^2}{a}.$$

Mental help can be derived in thinking of these phenomena by noting the sensation experienced in pulling a body through a limpid liquid like water. Mathematical analysis proves that the apparent inertia of a sphere is increased by one-half the

liquid mass displaced. This effect in the case of a sphere is independent of direction of the motion, because of the symmetry of the spherical form. If, however, a long cylinder be propelled in a liquid, the external inertia will clearly be dependent on the direction of the motion relative to the longest or shortest dimensions of the cylinder. If the motion be parallel to the axis of the cylinder, a small liquid displacement per unit distance of motion will result; while if the movement be at right angles to the axis, the maximum external inertia is experienced. Furthermore, if an infinite cylinder in a liquid (*e.g.*, a tube of force in the ether) be moved in any direction (except longitudinally, which means that it is not moved at all), it has external momentum only at right angles to its length. The energy of a tube we conceive as belonging to the body from which the tube originates, the inertia being due to the grip of these force tubes on the ether (to use an expression of J. J. Thomson).

In the discussion resulting in the conclusion that the electrical mass of a charged body in motion is proportional to $\frac{e^2}{a}$ the speed was supposed small in comparison to that of ether wave-motion, or the velocity of light.

In the case of an electron having a velocity of the same order of magnitude as that of light, as does a β-particle from a radio-atom, a further analysis is necessary. In this case the electrical mass will depend on the speed. A contemplation of Doeppler's principle will make this evident, since, as the charge changes position, there is a continuous though not instantaneous re-adjustment of the lines of force, which would radiate in all directions in straight paths if the charge were at rest. When the speed of the charged sphere has reached that of ether wave-motion the force tubes would all be equatorial and the inertia infinite.

If, then, it could be shown experimentally that the effective mass of a moving charged body is dependent on its speed, a part at least of this mass would have to be electrical, and due to this force-tube inertia. The experimental test of the question was made by Kaufmann when he measured the ratio $\left(\frac{e}{m}\right)$ in the case of the fast moving β-rays from radium. These rays have a higher average speed than cathode rays, and in Kauf-

mann's experiments rays of different speed were measured. The ratio $\left(\frac{e}{m}\right)$ varied from (1.31 to 0.63) $\times 10^7$, according to the speed of the particles.

Various formulas expressing the variation of mass with speed have been developed by J. J. Thomson, Heaviside, Searle, and others. To interpret his results Kaufmann used a formula developed by Abraham, as follows:

$$\frac{m}{m_0} = \frac{3}{4} \frac{1}{B^2}\left[\frac{1+B^2}{2B}\log\frac{1+B}{1-B} - 1\right],$$

in which

m_0 = mass of electron for slow speeds,

m = its mass at any speed,

$B = \frac{v}{V}$, where v is the speed of the electron and V that of light.

Referring now to Kaufmann's experimental results mentioned above, attention is directed to the following table:

I	II	III	IV
v	$\left(\frac{e}{m}\right)$	$\frac{m}{m_0}$ (Exp.)	$\frac{m}{m_0}$ (theory)
2.36×10^{10}	1.31×10^7	1.50	1.65
2.48 "	1.17 "	1.66	1.83
2.59 "	0.97 "	2.00	2.04
2.72 "	0.77 "	2.42	2.43
2.83 "	0.63 "	3.10	3.09

Column I gives five speed values actually measured of β-rays from radium. Column II gives the corresponding $\left(\frac{e}{m}\right)$ for each experiment. Column III gives the five respective values calculated from the results of experiment, of the ratio of the mass of radium β-particles to that of slow-moving electrons. For these letter particles $\left(\frac{e}{m_0}\right) = 1.95 \times 10^7$, the speed being comparatively slow, the charges being, of course, the same. In Column IV are found the ratios of the same masses calculated from the theoretical formula by substituting the different values of v given in Column I. Attention is called to the very close agreement be-

tween Columns III and IV, and also to the very weighty evidence thereby offered that the *total* mass of a moving corpuscle is electrical. It is surely worthy of note, too, that the agreement is closer for the higher speeds, which further strengthens one's belief in the theory that all the mass of an electron is electrical.

During the last year or two Professor Millikan,[2] of the University of Chicago, has made some very remarkable experiments tending to prove beyond possible question not only the truth of the kinetic theory of matter but the atomic nature of electricity. A further purpose of Millikan's work was to determine the most probable value of the electron, or one atom of negative electricity, in c.g.s. electrostatic units. He was able by observing the motions of electrified microscopic oil drops balanced against gravity in an electrical field, variable at will, to calculate the value of the electron to a high degree of accuracy. This value is said to be $(4.771 \pm 0.009) \times 10^{-10}$.

In the preceding discussion it has been assumed that electricity is only of one kind, this being the kind conventionally called negative. On this hypothesis an uncharged neutral molecule becomes negatively charged by the acquisition of an extra electron, and positively charged by the loss of one.

It will be remembered that the old two-fluid theory of electricity assumed three entities, positive electricity, negative electricity, and matter—uncharged matter having combined within it equal quantities of positive and negative electricity.

The one-fluid theory of Franklin assumed the existence of two entities, matter and positive electricity, the former in a neutral state having combined with it a certain normal quantity of the latter. A positively charged body was then one having more electricity than normal, and a negatively charged one had less.

The present theory assumes only one entity, the kind of electricity formerly called negative, atoms of matter being made up of different numbers and arrangements of these smaller atoms of negative electricity or electrons.

The following crude illustration may help to make this idea conceivable: For example, a whole city (a molecule) or group of cities (a mass) might be composed of separate buildings (the

[2] *Popular Science Monthly*, April, 1912.

atoms), either all alike (an element) or of many shapes and sizes (a compound), while every building might be made of bricks (the electrons) exactly alike in every respect. This notion that all matter in its simplest state is of only a single kind is, of course, not new, though the very forcible experimental evidence indicating such a state of affairs and that this ultimate unit of structural material is the atom of negative electricity has been offered within a comparatively short time. While it may be urged that another step has indeed been taken, but only deeper, into the mystery, yet, assuming the truth of the above conclusion, we find ourselves now face to face with a single problem instead of many, the solution of which would open wide the door to a comprehensive knowledge of many things now unknown and formerly unknowable.

The Acetylene-Electric Flame. C. F. LORENTZ. (*Electric World*, lxi, 511.)—When a powerful electric field is applied at right angles to a gas flame, the flame is deflected toward the cathode. There is no deflection until the anode is inside the invisible vapor mantle surounding the flame, and the deflection is accompanied by a small current through the flame. The deflection is due to the greater potential drop at the cathode, due to the greater mobility of the negative carriers. If a heavy current is passed, the action at the cathode is confined to one spot, which is heated sufficiently to emit ions copiously, and then the deflection ceases. If an arc discharge is passed at right angles to a flame carrying a large proportion of free carbon, there is a great increase in the luminosity of the flame. Acetylene is found to be a convenient illuminant, and curves are given showing the increased candle-power and the watts consumed. Direct current is more efficient than alternating, but the watt consumption for the increased candle-power is high. It is suggested that this type of flame is an efficient source of ultra-violet light.

Mortars and Concretes. H. BURCHARTZ. (*Mitt. Kgl. Materials, prüfungsamt*, xxxi, 80.)—The addition of trass slightly retards the setting of mortars and concretes, increases their resistance to water, greatly increases the strength of mixtures gauged with lime-water, and decreases the detrimental effect of soap solution. Lime-water increases the strength of trass mortars, but has no influence on the strength and water-tightness of mixtures which do not contain trass. Soap solution renders mortars and concretes water-tight and diminishes the hardening of mortars without trass, which weakening effect is counteracted by the addition of trass.

COLLOIDS AND CRYSTALS, THE TWO WORLDS OF MATTER.*

BY

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I.

WHEN a solid is brought into contact with a liquid the result depends upon the nature of both. There may be apparently an entire absence of interaction, as when rosin is shaken up with water or chalk with alcohol. Or, as when sugar is agitated with water, the solid may disappear, entering into solution in the liquid. The study of sugar solution shows quite clearly that the connection of the sugar molecules with each other has been completely destroyed. They are dispersed through the water very much as the molecules of a gas distribute themselves uniformly in a vacant space, and in both cases the permanence of the uniform dispersion is due to the incessant motion of the molecules. Were the molecules at rest, both the sugar and the gas would settle and form a layer on the bottom of the containing vessel.

However, the molecules of the sugar retain their structure intact, the action being limited to their dispersion. When salt, on the other hand, is dissolved in water, a further breakdown occurs, the molecule is separated and ions of sodium and of chlorine move about in the liquid. Both solutions freeze below 0° C. and boil above 100° C. The most important difference between them is that the salt solution conducts the electric current, while the sugar solution is as poor a conductor as water itself.

A fourth possibility presents itself when glue or gelatin is treated with water. The gelatin absorbs water, swells up and, under the influence of heat, dissolves, but the liquid freezes and boils at practically the same temperatures as pure water. The study of the solution shows that the dispersion is not molecular. The particles of gelatin in it are composed of variable

* Presented at the meeting of the Section of Physics and Chemistry held Thursday, April 10, 1913.

and rather large numbers of molecules. A system like this gelatin solution which presents a case of very fine but not molecular subdivision is called a *colloidal solution.* There are certain solids such as gelatin and dextrin (with water), rubber (with benzene and carbon disulphide), which, when they dissolve in liquids, are invariably dispersed in this way. Such solids may properly be referred to as *colloids.* They are all amorphous. Crystallized substances never yield colloidal solutions by mere spontaneous solution in a liquid. They always produce molecular or ionic dispersions. However, the phenomenon of colloidal solution is perfectly general, and crystallized substances can also be obtained in this condition, but not by mere solution.

It is an interesting fact that a substance which yields a colloidal solution with one solvent may form an ordinary molecular solution with another. Soap is an example. Its concentrated solution in water boils at about 100°, freezes at about 0°, and exhibits the behavior of a colloidal solution in general. On the contrary, a soap solution in alcohol shows the normal change in freezing, and boiling points corresponding to the molecular weight, and conducts itself in all respects like an ordinary molecular dispersion.

II.

Every one is familiar with the distinctions between solutions and suspensions. Suspensions are turbid in aspect, and the solid can be removed by letting it settle, or by filtration. Solutions are clear, dissolved matter does not subside and is unaffected by filtering. Colloidal solutions occupy an intermediate position.

Consider for a moment the effect of increasing subdivision on a suspension of finely-divided gold in water. So long as the diameter of the particles is much greater than a thousandth of a millimetre,[1] the system will be turbid and the gold will settle rapidly. But the wave-length of visible light ranges between 0.4 μ and 0.7 μ, and when the particles become smaller than this they can no longer reflect light and the liquid will appear clear. At the same time there will be a rapid falling off in the speed of settling. Stokes has derived a formula for the velocity of sub-

[1] It is usual to employ the symbol μ (the Greek letter mu) for the thousandth of a millimetre. In the same way $\mu\,\mu$ indicates the millionth of a millimetre.

sidence, v, of small spheres of radius R and density S falling in a liquid of density S' and internal friction f under the force of gravity g:

$$V = \frac{2}{9} g (s - s') \frac{R^2}{f}$$

Substituting the proper values for gold and water and assuming a radius of μ for the particles, the value for V is about 14 centimetres per hour. This means, of course, that the system would be a coarse suspension and would clear up at once. But when $R = 10\ \mu\ \mu$, V is only about a centimetre a month. This begins already to be fairly permanent. It must be remembered that the high density of gold (19.5) increases the rapidity of subsidence. If we make the calculation for $S = 3$, which is about the density of arsenious sulphide, V comes out only about a millimetre a month.

So much for calculation. Now what are the facts? As a matter of fact, the dispersed substance in a colloidal solution does not settle at all, so long as the subdivision is maintained. Colloidal gold solutions have been preserved unchanged for years. I have a solution of arsenious sulphide which has remained apparently unchanged for three years and whose countless particles can readily be seen, engaged in their incessant Brownian movement, with an ordinary oil immersion lens. Whenever settling does occur, it is preceded by the aggregation of the particles into larger particles, which finally attain a diameter of μ or over, and slowly subside.

Here, then, is an apparent discrepancy between Stokes's law and the facts. The law informs us that the speed of subsidence decreases rapidly with decreasing radius of the particles, but it does not lead us to expect the total absence of settling which presents itself when the average radius is 10 $\mu\ \mu$ or thereabouts.

The explanation, of course, is molecular motion, or, in other words, *heat*. The particles are battered, on all sides, by a hailstorm of molecular impacts. If the particle is large, the blows of the molecules of the solvent in different directions neutralize each other. But when the particle is not so very much larger than the molecules themselves a molecule striking, say, on the left, will give the particle a very perceptible push toward the right, "just as a cork follows better than a large ship the motion

of the waves of the sea."[2] As the dimensions of the particle approach the molecular dimensions it begins to behave like a molecule and is swept along in the endless molecular movement. The cause which prevents the particles in a colloidal solution from settling is in no way different from the cause which prevents the earth's atmosphere from subsiding to a snowy layer a few feet deep on the surface of the planet.

It is worth remembering, also, that the particles of the dispersed phase ordinarily possess an electric charge, which is usually negative. The effect of the repulsion of these similar charges would be to preserve the distribution of the particles throughout the liquid. It is a fact that, when the charges are removed, the system becomes instable and subsidence—preceded by coalescence of the small particles—readily, but not necessarily, occurs.

III.

On the subject of the classification of colloid systems we must be very brief. One proposal subdivides them into *suspensoids*, such as the sols[3] of gold and arsenious sulphide, in which the dispersed phase is solid, and *emulsoids*, in which the dispersed phase is liquid. This classification would appear to be an attempt to extend the familiar distinction between liquid and solid to a domain in which that distinction has little if any meaning. To assert that a thing is solid is to say that it has a definite shape, which it retains with some persistence. There is not the slightest reason to think that the particles in a gold sol are solid. It is usual to assume that they are spherical, but this is done merely because it is the simplest assumption to make. There are faint indications that they really have the form of leaflets or of little rods, but they appear in the ultra-microscope simply as brilliant dancing points, and in reality we know nothing whatever about their shape. In connection with this it is interesting to recall the fact that the formation of a crystal begins with the appearance of minute liquid spheres (globulites)[4], which pass

[2] Perrin.

[3] Thomas Graham introduced the term sol as an abbreviation for colloidal solution.

[4] Fink, "Poggendorff's Annalen," vol. 46, p. 258 (1839); Schmidt, "Liebig's Annalen der Chemie," vol. 53, p. 171 (1845); Frankenheim, "Poggendorff's Annalen," vol. 111, p. 1 (1860).

through several stages (margarites, longulites, etc.) before the crystal is formed. It seems possible that, under such enormous subdivision, cohesion retires into the background and surface tension assumes the chief rôle, so that the gold particles are rather to be compared to minute drops than to little crystals.

Enough has been said to make clear the uncertainty which attaches to the attempt to classify colloid solutions according to the state of aggregation of the particles. A better classification is into *reversible* and *irreversible* colloids, according to the way in which the dissolved substance behaves when separated from the solution. Thus, when a gelatin solution is evaporated until it "sets" it is only necessary to warm the jelly with water to obtain it again in colloid solution. Gelatin is a typical reversible colloid. But when the gold is caused to separate from a gold sol—which can easily be brought about by adding any electrolyte to the sol—the gold will not again enter into colloidal solution. Shaking or warming with water gives a mere suspension, which settles at once. Gold is an *irreversible* colloid. The distinction is fundamental. Many organic colloids are reversible, while it is rather the habit of the inorganic colloids to behave in the irreversible way.

IV.

In order to prepare a sol containing an irreversible colloid all that is necessary is to reduce the solid to extreme subdivision in a liquid in which it is insoluble. The electric arc furnishes a rapid and simple method.[5] Two gold wires about 2 mm. thick are connected with a 220-volt circuit and brought together under distilled water. A 110-volt circuit can be used, but more patience is required. Sols of platinum, silver, copper, and other metals can be made in the same way. By related electrical methods, using such liquids as pentane and anhydrous ether, Svedberg[6] obtained sols of all five of the alkali metals. The colors of the sols agreed with those of the vapors of the corresponding metals.

[5] Bredig, *Zeitschrift für angewandte Chemie*, 1898, p. 951. For a full account of Bredig's work with the platinum sol see *Zeitschrift für physikalische Chemie*, vol. 31, pp. 258–353 (1899).

[6] *Berichte der deutschen chemischen Gesellschaft*, vol. 38, p. 3616 (1905).

Chemical reduction of a salt of a metal furnishes another method which has been largely employed by Zsigmondy[7] and other investigators. For instance, a very dilute solution of auric chloride is mixed with such reducing agents as formaldehyde, hydroxylamine or an ethereal solution of phosphorus. The gold sols obtained in this way are usually red by transmitted light, the particles being bright green and very much smaller than in the sols obtained by the electrical method.

By various chemical methods, which lack of space forbids us to discuss, sols of sulphides (CdS, As_2S_3, Sb_2S_3, etc.) and oxides (Fe_2O_3, Al_2O_3) can be obtained. The sol of aluminum oxide is important on account of its connection with dyeing and mordanting. The formation of the blood-red sol of ferric oxide by adding a concentrated solution of ferric chloride to about 50 volumes of boiling distilled water is a simple and beautiful lecture experiment.

In making colloidal solutions of *salts,* the essential thing is to mix dilute solutions of the precipitants, using a liquid in which the insolubility of the product is as complete as possible. Thus, in mixing very dilute solutions of sodium sulphate and barium chloride, a crystalline precipitate is usually obtained. The reason is that barium sulphate possesses a very slight but real solubility in water. Hence the liquid in contact with the particles first formed contains enough barium sulphate to nourish their growth and allow them to develop to crystals. If alcohol is added to the sulphate, before the barium chloride is introduced, the solubility of the barium sulphate is greatly reduced, and it is obtained in colloidal solution without difficulty.

In the same way if we mix water solutions of sodium hydroxide and of hydrochloric acid we obtain merely an ordinary solution of common salt. But if salt is produced by a reaction between organic compounds in a liquid in which the sodium chloride is insoluble, then a colloidal solution is obtained. For instance, when chlor-acetic ester interacts with sodio-malonic ester a grayish opalescent sol of sodium chloride in ethenyl tri-carboxylic ester results: $CH_2Cl\ COOC_2H_5 + CHNa(COOC_2H_5)_2 = CH_2(COOC_2H_5) - CH(COOC_2H_5)_2 + NaCl$.

[7] See his monograph, "Zur Erkentniss der Kolloide" (Jena, 1905), which has been translated by Jerome Alexander.

At low temperatures, in such liquids as toluene and chloroform, even *ice* has been obtained in colloidal solution.

V.

The most striking property of the reversible colloids is that they are able to communicate their reversibility to the irreversible ones. Thus, if a trace of gelatin is added to a gold solution, the gold becomes much more difficult to coagulate by electrolytes, and when coagulated it can be dispersed again by merely warming with water. This curious protective action is exerted, in greatly varying degree, by most reversible colloids. Direct study of the phenomenon with the ultra-microscope shows that the view frequently expressed that the gelatin envelops or forms a film around the gold particles is incorrect. What actually happens seems to be a direct combination between gelatin particles and gold particles, which then pass through the reversible changes together.

Protective colloids enjoy a wide practical application. In the manufacture of photographic films the gelatin retards the crystallization of the silver bromide. Ink often contains a colloid which prevents the pigment from settling. The lubricant "aqua dag" put in the market by the Acheson Company consists of finely-divided artificial graphite, held up by a protective colloid. Clay is made plastic for the potter by an empirical process which involves the action of protective colloids derived from decaying vegetable matter. The addition of gelatin in making ice cream depends upon its protective action in preventing the growth of ice crystals, which would make the product "gritty." Without doubt protective action plays an important rôle in the cleansing action of soap. This has been made clear by some recent experiments of Spring.[8] Lampblack, freed from oil by long washing with alcohol, ether, and benzene, forms a rather stable suspension in water, but the lampblack is detained by a paper filter. If the filter is now reversed, so that the blackened surface is outward, and water poured through it, the lampblack is not removed, but a dilute soap solution removes the coating and cleanses the filter at once. Finally, lampblack suspended—or colloidally

[8] *Kolloid Zeitschrift*, vol. 4, p. 161 (1909); *Kolloid Zeitschrift*, vol. 6, pp. 11, 109, 164 (1910).

dissolved—in soap solution, passes through a filter unchanged. It is of much practical interest that there is a well-marked optimum in the concentration of the soap required to protect the lampblack. A one per cent. soap solution is the most efficient. In two per cent. soap solution lampblack sinks about as rapidly as in pure water.

VI.

We have already considered the probable actual condition of the particles in a colloidal solution and have concluded that, for the present, no very definite information is obtainable about the matter. We must now return, for a moment, to the subject in order to allude to the thesis so brilliantly advocated by van Weimarn, the Russian investigator, who holds that the particles are of necessity minute crystals and that there is, in fact, no such thing as amorphous matter. He even goes so far as to state that substances like air and water are in a "dynamic crypto-crystalline condition," though I have been unable to understand what he means by this statement.

Briefly, the evidence that van Weimarn adduces to the support of his hypothesis is:

(1) That colloid particles will grow to crystals if provided with the proper nourishment, namely, a dilute solution of the same substance.

(2) That colloid particles are capable, when introduced into a supersaturated solution of the same substance, of discharging the supersaturation and inducing the formation of crystals.

Those who desire to follow this matter further should read van Weimarn's little book, "Grundzüge der Dispersoidchemie," after which they will find themselves very much interested, but somewhat unconvinced. Let me hasten to add that I have not the least desire to undervalue the brilliant experimental work of the Russian chemist. It is, in fact, precisely by the conception of more or less daring hypotheses, and the working out of their consequences, that our science achieves its endless victory over the nescience about us.

VII.

We have seen that the wave-lengths of the visible radiations are comprised between 0.4 μ and 0.7 μ. With objects much

smaller, the ordinary microsopic method ceases to be applicable. Using ultra-violet radiation for illumination, quartz lenses in the microscope, and receiving the image with the photographic plate instead of the eye, it is possible to advance a step further in the domain of the infinitesimal, but only a step, and there are obvious objections to the proceeding. Since some of the particles in colloidal solutions are only 0.006 μ in diameter, we can never hope to see them as little bodies subtending a visual angle. The *ultra-microscope*—the powerful instrument of investigation to which most of our knowledge of colloid systems is due—renounces this idea and makes the particles visible merely as glittering points on a black background. The sol is placed in a small rectangular glass trough and a horizontal beam of arc light or sunlight focussed in it. The microscope is placed vertically above the trough. It will at once be seen that there are two fundamental things about the instrument: to provide intense illumination, and to make sure that no light enters the microscope except the rays which emanate from the particles. The principle is simple, but the system of diaphragms and lenses needed to secure the second object makes the ultra-microscope an elaborate and expensive instrument in practice.

Cotton and Mouton[9] achieve the same end in a different way. The illumination (arc or sunlight) is thrown up from below by a paraboloid reflector so ground that all rays, *except those diffracted by the particles,* are totally reflected from the cover-glass over the sol. This instrument is simple, easily adjusted and cheap. It is made commercially by the firm of Zeiss. It would seem to be admirably adapted to school purposes. In fact, after a look into the ultra-microscope, the study of the molecular topics ceases to be drudgery and becomes a positive intellectual need.

VIII.

Even a brief glance at the subject of colloid systems must at least mention the classic work of Perrin[10] on the distribution of

[9] *Compt. Rendus,* vol. 136, p. 1657 (1903).

[10] *Annales de Chimie et de Physique,* 3d series, vol. 18, p. 5 (1909). There is a German translation by Donau in *Kolloidchemische Beihefte,* vol. 1, p. 1 (1910). An English translation by Soddy has appeared in book form under the title "The Brownian Movement and Molecular Reality."

the particles in suspensions of gamboge and mastic. He succeeded, by an ingenious and simple method, in preparing emulsions of gamboge in water in which the spherical yellow granules were all of the same diameter. If we consider a mass of such a liquid in a tube, it is clear that the granules, if at rest, would, since they are denser than water, all fall to the bottom. The fact that they remain suspended is due to their movement. In other words, the state of things is the same as in the earth's atmosphere, and just as the molecules are more crowded near the earth's surface, so the granules of gamboge must be more numerous near the bottom of the liquid than in the upper layers. Perrin verified this prediction by direct counting of the granules under the microscope. The barometric formula which describes the progressive rarefaction of air with increasing height also describes the distribution of the granules in Perrin's uniform emulsions. The only difference is that, while the aviator must ascend six kilometres in order to reach air half as dense as at sea level, the same effect is produced, in Perrin's emulsion, by an ascent of 0.1 millimetre.

That the mean energy of rotation of a molecule must be equal to its mean energy of translation is one of the chief propositions of the kinetic theory. Perrin has proved this by direct measurement of the rotation of granules under the microscope. For this purpose, large granules (15 μ) of mastic were employed. These are far too heavy to remain suspended in water, so a solution of urea was used. Fortunately, the granules contain little inclusions which make it possible to measure their rotation.

These are only two of many fundamental results contained in this wonderful memoir. Van't Hoff extended the gas laws to solutions. Perrin has now proved them to be valid for systems in which the moving particles are visible realities. Let us end by quoting one of the sentences of his conclusion:

"La découverte de telles relations marque le point où s'élève, dans notre conscience scientifique, la réalité moléculaire sous-jacente."

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE METRIC CARAT.†

BEGINNING July 1, 1913, the Bureau of Standards will recognize the metric carat of 200 milligrammes as the unit of weight for diamonds and other precious stones, and will use this unit for purposes of certification of all carat weights submitted to the Bureau for test. On the same date the Treasury Department of the United States Government will also begin the use of this unit in the customs service for the levying of import duties on precious stones. This unit will also be put into commercial use in the United States on this date by practically all the dealers in gems and precious stones through the efforts of a committee representing all the principal firms handling gems.

The Bureau has therefore taken this opportunity to issue a circular giving tables of the relations between the carat weight in former use in this country and the new metric carat, together with other information that may be of interest at this time in connection with the subject.

The carat weight in use in different countries has, in the past, differed greatly, scarcely any two countries of importance having the same standard. Even within the United States there has not been agreement in the standard used, the various makers of weights using slightly different quantities as a standard. This has led to a great deal of confusion in the weighing of gems, which has been the more serious because of the great value of the article.

Recently, however, the movement for the adoption of a uniform standard has met with increasing success, and the metric carat of 200 milligrammes has been adopted by Spain, Italy, Bulgaria, Denmark, Norway, Japan, Portugal, Roumania, Switzerland, Sweden, France, Germany, and Holland, while considerable progress has been made toward its adoption in England and Belgium.

* Communicated by the Bureau.

† Circular of the Bureau of Standards, No. 43.

The carat which has been in use heretofore in the United States, while varying, has been nearer the value 205.3 milligrammes than any other. This value has therefore been taken in making up the tables of equivalents given in this circular. This old carat has usually been subdivided on the binary system, the smallest subdivision used being, usually, one sixty-fourth of the carat. One of the improvements introduced with the new system is the subdivision of it on the decimal system. Tables are given both for the conversion of fractions of an old carat to decimals of the metric carat and for each whole carat from 1 to 100 in terms of the new, and *vice versa*.

Suggestions are also given for the improvement of weighings of precious stones, including the necessary features of a good balance, its use and care, the characteristics of the best kind of weights for the purpose, the method of their adjustment and the tolerances that will be allowed under the Bureau's Class C tests of such weights, the protection and handling of the weights and their certification. It is recommended that a small letter "c" without a period be used as an abbreviation for the metric carat in conformity with the system of abbreviations used in the metric system, the abbreviation "car." having been used heretofore for the old carat.

METHODS OF ANALYSIS OF STANDARD ANALYZED SAMPLES.*

A NEW edition of Circular No. 14 gives the revised methods of analyses employed in the preparation of the series of standard analyzed samples issued by the Bureau of Standards for checking the accuracy of commercial analyses. Some of the Bureau's methods have undergone modification from time to time and as given apply mainly to the irons and steels recently issued.

The earlier samples were analyzed usually only by the rapid technical methods used more or less generally by the steel trade. The analyses made by the other coöperating chemists were mostly of the same type. The object on the one hand was to indicate the order of agreement which might be expected from careful analysis, using these methods and working on a homo-

* Bureau of Standards Circular No. 14, 4th edition.

geneous material, and on the other hand to supply samples of which the composition was known within the limits of error indicated by the results published on the certificates It is therefore emphasized here that the Bureau's analyzed irons and steels are "standardized" only in this sense. In other words, the figures on the certificates are perhaps to be regarded as a criterion of the existing state of the analytical chemistry of this class of materials, and of methods, and they no doubt represent fairly well the result which may be expected by attempting to fix the composition of such materials in this way. It should be remembered, however, that the composition so determined is not necessarily the absolute or correct one, and that judgment should be used in the application of the data afforded by the certificates. An illustration will make this clear.

Scrutiny of all the earlier iron and steel certificates issued shows that the color method for manganese has furnished results over 5 per cent. higher on the average than were obtained by the other methods combined. Without raising the question whether the average of the color results or that of the others is nearer the truth, it is clear that both cannot be correct, and that their "general average" must probably be in error. Hence, an analyst, using the samples, is justified in respecting the "general average" if experience has convinced him that the average for any particular one of the methods tabulated is worthy of greater credence. Further, for instance, it would be manifestly wrong to use any one of the general averages for manganese (possibly in error by one or more per cent. of the manganese) for the standardization of a volumetric solution that is to be used for a ferromanganese alloy or a manganese ore.

No doubt the above cautions will be found applicable to some of the other common elements as well as to manganese, but, owing to the much smaller percentages of most of those others, their errors are not as a rule so immediately apparent nor so amenable to the corrective study which the Bureau hopes to take up in time.

Closer approximation to the truth might be obtained through determinations by a greater variety of technical methods, or with better promise of success by the longer and perhaps more exact methods not generally used for technical work, or by correcting for some more or less obvious sources of error often

overlooked by the technical analyst. The amount of work to be thus expended on a given sample must be regulated by the importance of higher accuracy to those who use the sample. The Bureau endeavors to have the results by its own chemists well within the limits of error permissible in practical work. These in turn are governed by such factors as the degree of segregation in ingots, castings, etc., the difficulties of sampling large lots of material, etc. At present it is believed that in the steel and iron industry most of the technical analytical methods are capable of yielding results quite up to, if not in advance of, the requirements of practice.

THE TESTING OF MATERIALS.*

MANY inquiries are received by the Bureau of Standards regarding the testing of materials. A new circular now in press is designed to furnish information upon some of the more general aspects of this branch of the Bureau's work. The circular is intended mainly for the user or buyer of materials rather than the industrial expert. The aim is to outline briefly with respect to each class of material the tests usually made, the conditions under which such work is undertaken, and some of the limitations due to the status of technical knowledge. Such testing is mainly for the Government Departments or where an authoritative test is required.

The testing of materials serves two important and distinct purposes: First, to ascertain whether or not they comply with specifications; and, second, to add to the general fund of knowledge regarding them. When done with both objects in view it ceases to be of merely transient value for the immediate case in hand, important as this may be, but adds to the world's useful knowledge of the materials. Data accumulate rapidly in the regular work of the testing laboratory, and when properly correlated they yield information of permanent value in the industries.

The utility of materials depends upon the nature, magnitude, and stability of their properties. To determine these is the object of the testing of materials. For a complete study of the properties of a material all of its properties would have to be

* Bureau of Standards Circular No. 45.

studied through all ranges of conditions. Considerations of economy generally make such full tests impracticable, although the conviction is growing that the systematic study of the properties of materials would be a most effective means of technical progress.

The degree of accuracy to be sought becomes a very practical matter in a testing laboratory. The time and labor involved in such tests increase out of proportion as the limits of attainable accuracy are approached. For the determination of physical constants or fundamental properties of materials the degree of accuracy sought may be the maximum possible. For example, a minute may suffice to determine the density of alcohol for commercial purposes by means of a hydrometer. Months, however, may be well spent in a precise determination of its density as a physical constant of great technical importance. In general the degree of accuracy striven for should be that which is strictly good enough for the purpose in hand—whether the work be routine testing or scientific research. The selection of the degree of accuracy to be sought for in each case requires the experience and judgment of the specialist.

The time has passed when the strength of materials can be left to guesswork or even to intelligent opinion alone. With the rapid increase in the height of buildings, length of span for bridges, and speed of transportation, new problems in safety and efficiency arise. The testing laboratory can test these materials by sample in advance of their use, and by means of the strain gauge can determine the net strain of the structure during its construction and after erection or assembling. Suitable tests during and after construction might be prescribed in building or inspection regulations and made part of the original specification in all cases. Under these circumstances the responsibility for failure of structures must rest with those who knowingly omit adequate tests where such are available.

The circular treats of the more usual tests applied to the various materials. In many cases the best methods for testing have yet to be devised. As rapidly as practicable, the Bureau is selecting or developing standard methods of testing each useful quality of materials. This leads directly to the establishment of specifications or standards of quality.

Ideal standards of quality in most cases are still imprac-

ticable through lack of data, and the practical step has been the tentative specification. The specification is designed to obtain the quality best suited to the case in hand, and usually reflects the status of knowledge upon this subject. To the extent that it embodies the results of experience, it is the best that can be done until rigorous standards of quality are developed. Inflexible specifications retard technical progress; but if allowed to advance apace with new technical knowledge, the specification becomes a distinct aid to such progress.

With the large variety of tests which may be made of a given material those should be selected which suffice to show with commercial accuracy its fitness for the purpose in view. Economy dictates this limitation, since in many cases the time and labor needed for more elaborate tests would make them prohibitive, and nullify the economic value of such testing. Tests of quality may be made with varying degrees of completeness except where existing specifications define the tests to be applied. Even such tests may be modified in emergencies.

A brief outline of tests applicable to the several classes of material will be found in this circular. The treatment, in the nature of the case, is usually incomplete. Where definite tests cannot yet be announced, the Bureau will endeavor to furnish information and possibly arrange special tests. In making these tests and investigations of materials for the Government, and in special cases for others, the Bureau secures much valuable information as to the nature and use of the materials and the specifications and methods of testing. This is always available to manufacturers, private testing laboratories, and the public. While the results of any single test may be for a particular object, the general information which accumulates at the Bureau is of wider interest and application.

Among the sections of the circular may be mentioned Metals, Cement, Ceramics, Lime, Stone, Paints and Paint Materials, Bituminous Material, Inks, Paper, Textiles, Rubber, Leather, Lubricating Oils and Greases, Chemicals, and Miscellaneous and Technical Materials.

Copies of the circular may be obtained by those interested upon request.

HIGH-FREQUENCY AMMETERS.

By J. H. Dellinger.

THE following is an abstract of an extended paper dealing with the measurement of high-frequency currents, to be published in the Bulletin * of the Bureau of Standards.

For the measurement of current at radiotelegraphic frequencies, 50,000 to 2,000,000 cycles per second, it is general practice to use the hot-wire ammeter or a modification of it. Its superiority is due to the simplicity of form which the portion of the circuit within the instrument may have, permitting a minimum of self-inductance and capacity. When the instrument is required to carry relatively large currents, a simple single wire is not sufficient, and more than one elementary path must be provided for the current. Then the current distribution, and consequently the indicated current, changes as the frequency is varied, because at low frequencies the current distribution is determined solely by the resistance, while at high frequencies the inductances predominate. There are three general types of ammeters for large currents of high frequency: (*a*) that employing wires in parallel, (*b*) the so-called unshunted ammeter in which a single wire has different portions of its length in parallel, and (*c*) the ammeter employing thin metal strips. All types in use are found to be subject to serious errors at radiotelegraphic frequencies.

In the case of the parallel wire ammeter, mutual inductances between parts, which had hitherto been supposed negligible, are the determining factor in the change of current distribution. It is an interesting fact that these changes come just in the range of radiotelegraphic frequencies. In the so-called unshunted ammeter the errors are chiefly due to the self-inductances of parts other than the hot wire. They can be minimized by symmetrical location of the current leads. In the strip ammeter the terminal blocks have been found to be the source of large errors. These are reduced by proper shaping of the blocks.

One effective means of reducing the errors of these ammeters at high frequencies is by using working parts of high resistance,—*i.e.*, metal which is both very thin and of high resistivity.

* Bureau of Standards Scientific Paper No. 206.

Another expediency which was found successful was to change the design so that the deflections depended on the entire heat production in the instrument instead of on that in one branch of its circuit. Still another method of improvement is to arrange the working parts (either wires or strips) as equidistant elements of a cylinder, so that each has the same set of mutual inductances. Even this design, in common with the others, is subject to an error which has hitherto been overlooked. It is very difficult to obtain very thin wires or strips of uniform cross-section, and this variation results in the resistances of elements being unequal while the inductances are substantially equal.

The induction of eddy currents in neighboring masses of metal is found to cause no error. Inductive action of the leads near an instrument in some cases appreciably affects the readings. The distributed capacity of the circuits within the instruments is found to cause no error, but the capacity of auxiliary parts produces an appreciable effect at the highest frequency used, 1,500,000 cycles per second. This effect was very striking, two instruments in series carrying different amounts of current. A way was found to eliminate the effect, for the purposes of ammeter comparison.

The experiments on the various types of instrument were corroborated by theoretical calculation. The formulas for self and mutual inductances of short parts of a circuit were shown to hold for this kind of work. From the standpoint of pure science, this is one of the most interesting results of the investigation.

The Influence of Hot Caustic Lye on the Strength of Cotton Goods. R. BUDE. (*Färber. Zeit.*, xxiv, 159.)—Gray cotton cloth was treated with caustic lye of 8°, 12°, and 18° Bé., containing 5.29, 8.00, and 12.64 per cent. NaOH respectively, no tension being applied. After washing thoroughly, the cloth was boiled under pressure and bleached. Strength determinations were made on warp and weft threads. Duplicate tests were made on heavier cloth, and also with the same cloth after dyeing and finishing. In all cases the strength was increased. Also the loss in weight decreased as the concentration of the caustic soda increased. The increased strength is probably due to the formation of a cellulose hydrate, the factors which influence the change probably operating through their effect on the osmotic pressure of the solution.

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CURRENT TOPICS

On the Troubles which Certain Lightning Conductors, Called "Niagaras," May Cause to Neighboring Postal and Telegraphic Apparatus. J. VIOLLE. (*Comptes Rendus*, clvi, 520.)—The Postal Administration of France has hitherto followed the course indicated by Melsens for applying the principles of the Faraday cage to lightning conductors protecting buildings. Modern wireless researches have demonstrated the vital importance of the earth connection for currents of very high frequency, and it is now recognized that many lightning conductors are inefficient from indifferent earths, though almost perfect according to old ideas. Further, the ohmic resistance of such a conductor is secondary, its surface, and freedom from bends, being of the greatest importance. An electric "niagara" consists of a long strip of electrolytic copper terminating above and below in clusters of copper points, those at the bottom dipping into a sheet of water. During storms, atmospheric electricity is continuously discharged through the points, whence the name "niagara." No aërial telephone wire should be within 20 metres of such niagaras, or disturbances may result.

Disintegration of Metals at High Temperatures. J. H. T. ROBERTS. (*Phil. Mag.*, xxv, 270.)—The theory has been advanced that the disintegration of the platinum metals was due to direct oxidation. Since platinum does not, under any conditions, combine directly with oxygen, it is generally assumed that the influence of oxygen can only be catalytic, and, moreover, there are certain experimental facts which apparently tend to disprove the theory that the disintegration is due to direct oxidation. In these experiments, in which Wilson's condensation method is adopted, the wire is not placed in the expansion chamber, but in a separate chamber, so that no water drops can fall upon it. The wire is heated by a current developed from an alternator and transformer set. On their way to the expansion chamber the nuclei pass through an annular space, 2 mm. wide, between two brass tubes insulated from one another, the outer one earthed, the inner at —230 volts. There are two well-marked conditions governing the production of nuclei: (1) The recent history of the wire previous to the experiments. (2) The length of time since the commencement of experiments. There are two sets of nuclei: the first, got rid of after continuous experimenting, depend on the presence of hydrogen and other gases in the wire; the second depends on the presence of oxygen surrounding the wire: the second set are never obtained

below a certain temperature. The metals experimented upon were platinum, palladium, rhodium, ruthenium, and iridium. Platinum begins to disintegrate at as low a temperature as 500° C., but no loss of weight could be detected even after days of heating. The disintegration comes within the range of the balance between 1000° C. and 1100° C. The second set of nuclei, even at 500° C., are very persistent, and do not change in size or character, being produced in pure oxygen, no matter how long the heating has been continued; they are not produced in the absence of oxygen. This shows that they probably are not either particles of the metal brought off by the escaping gas or traces of compounds of different gases. The rate of the loss of weight of the platinum wire is roughly proportional to the oxygen pressure, which points to the formation of an endothermic oxide. Experiments in a constant-volume gas chamber, in which the loss of platinum to the loss of oxygen is determined, give results which in the case of air approximate 2 Pt: O, and in the case of oxygen Pt: 2O. It does not seem probable that this large amount of oxygen is simply adsorbed; it must be combined chemically, or, at any rate, for the greater part. During the cooling of the oxide after its formation at the hot wire some decomposition takes place, and the amount of the decomposition will be greater the lower the oxygen pressure. If we assume that the oxygen adsorbed by the deposit is small, the composition of the oxide in the experiments with oxygen must be either PtO_2 or some higher oxide. If the oxide is also present in the deposit in air, there must be a considerable amount of metallic platinum mixed with it, being the result of dissociation of the oxide during cooling. The formation of an endothermic volatile and dissociable oxide not only explains all the observed facts, but will also explain certain facts in the discharge of negative and positive electricity from hot platinum wires at low pressures.

Change of Volume of Ceramic Raw Materials in Burning. R. RIEKE and K. ENDELL. (*Silikat-Zeits.*, i. 48, 67, 85.)—There are three causes for volume alteration: (1) Transformation from a crystalline to the amorphous state; (2) decomposition into new compounds, and (3) transformation into another crystalline system. Feldspar belongs to the first of these types, kaolin to the second, and quartz to the third. The behavior of various forms of silica during heating is described and the results are applied to practical ceramics. Different sources of raw material, such as the interchange of flint and quartz, undoubtedly affect the behavior of the body, quite apart from their degree of subdivision, and the case may be further complicated by transformation from one form of silica to another during burning. The action of glaze on body is greater when the body is compounded with flint than when compounded with quartz or cristobalite. There are numerous references to previous investigations.

Resistance of Thick Cylinders to Rupture. MALAVAL. (*Rev. de Métallurgie*, x, 214.)—In a tube of the proportions of gun practice, the thickness about equal to the calibre, there are two distinct periods besides the elastic range. This is followed by the range of semi-elasticity or partial failure, which is of sensibly the same duration in stress. With increasing applied pressures the area of overstressed metal widens radially outwards. Thus if the pressure is released the outer elastic zone is prevented from returning completely to its original shape by the permanent deformation of the inner plastic zone. The mutual action causes the unloaded tube to be stressed in tension in the outer region and in compression in the inner, so that it is in the condition of an ideal shrunk composite tube—*i.e.*, one with an infinite number of indefinitely thin components whose mutual pressures are such that under rising internal pressure all parts reach the elastic limit simultaneously and bear equal parts of the load. The semi-elastic period ceases when the outside layer reaches the limit of elastic deformation and is followed by the periods of general failure. During this period, covering an increase of resistance much greater than those of the first two periods, all parts show an increase of resistance, the inner region being in compression and the outer in tension. It follows that the metal, whose capacity for deformation is greater in compression than in tension, can withstand very considerable internal strains. It is concluded that the ordinary shrinking process might be replaced advantageously by one involving initial overstraining of a solid tube. A gun so constructed would withstand a pressure of over 1500 kilogrammes per square centimetre (213,300 pounds per square inch).

Graphite Industry of Madagascar. ANON. (*Board of Trade Journ.*, June 12, 1913.)—His Majesty's Consul at Antananarivo reports, on the authority of the Chief of the Mining Department of Madagascar, that the graphite industry in the island is making considerable progress, the quantity exported during the first quarter of the year amounting to 980 kilogrammes, as compared with 474 kilogrammes during the corresponding period of last year, and 259 kilogrammes for the corresponding period of 1911. It is believed that by 1916 there will be 20 metric tons exported annually.

Motor Car Bronzes. ANON. (*Metal Ind.*, ii, 7, 298.)—The American Society of Automobile Engineers has adopted the following specification for bronzes: Hard Bronze—Copper, 87–88 per cent.; tin, 0.5 to 10.5 per cent.; and zinc, 1.5 to 2.5 per cent. Gear Bronze—Copper, 88–89 per cent.; tin, 11 to 12 per cent., and phosphorus, 0.15 to 0.30 per cent. The hard bronze is similar to the United States Government bronze *G*, and has a tensile strength of approximately 35,000 pounds per square inch. The gear bronze is commonly known as English gear bronze.

Argon and its Production. SIR W. RAMSAY. (*Chem. Trade Jour.*, lii, 595.)—After referring to earlier work on the action of niton (radium emanation) on various substances, and the formation of helium and neon by the bombardment of the glass of a vacuum tube by cathode rays in the presence of hydrogen, the writer states that he has confirmed the results of Collie and Patterson, and believed that under the experimental conditions dry hydrogen polymerized into helium, while oxygen was necessary for producing neon, which might be derived from moisture or from the bombarded glass. On allowing the electric discharge to pass for five or six hours between the aluminum cathode and an anode of aluminum coated with sulphur in a vacuum tube into which dry hydrogen was introduced, evidence was obtained of the formation of argon, but no trace of neon or helium could be detected. In an analogous experiment, using selenium instead of sulphur, the gas obtained, when examined spectroscopically, showed very faintly the characteristic yellow and green lines of krypton.

Annealing of Hardened Products. L. GUILLET. (*Rev. Mét.*, x, 665.)—The tensile strength, elastic limit, and elongation of hardened nickel and steel were determined in the original condition, and after annealing in a salt bath at temperatures from 100° C. to 900° C., and the results are tabulated and graphically illustrated. It is shown that the first deflection from the original as the result of annealing occurs at about 400° C., with a marked change between 700° C. and 750° C., and the change was greatest in the case of the elongation. The influence of time on the effect of annealing was also investigated, and the conclusions reached are: The time of annealing has no influence on the elongation, while the breaking strain is slightly lowered in the case of nickel and more so in hard steel, especially if the time be prolonged, although the result may be influenced by the surface decarburization produced. In all cases the influence of time is very slight, in contradiction to generally-accepted views.

Silit. R. PERLEWITZ. (*Electrotechn. Zeitschr.*, xxxiv, 263.)—Silit is a new resistance material made by Gebr. Siemens & Co. It consists essentially of silicon carbide, and is prepared according to methods covered by several patents. The original idea was to use a mixture of silicon and carborundum, together with some organic binding material, but the result of the subsequent processes was to obtain a mixture of some of the silicon carbides. Several instances of the application of the material are given. It can be used as a resistance material at high temperatures, and specially in connection with heating appliances, since it is not affected by temperatures up to 1400° C. Photographs and descriptions are given of various pieces of apparatus in which it is used.

"Cellit": A Non-inflammable Cinematograph Film. C. R. HENNINGS. (*Phot. Journ.*, liii, 10.)—The celluloid of the ordinary cinematograph film is a compound of nitrocellulose and camphor. It is very combustible, burns rapidly and in such a way as to quickly involve surrounding objects, while the gases evolved include carbon monoxide, nitrogen oxide, and hydrocyanic acid (?), and are highly poisonous. The "cellit" film is practically non-inflammable, and, so far as the adhesion of the emulsion and the suppleness of the base are concerned, the two types of film are identical. Their outward appearance is practically identical. Cellit expands more than the ordinary film in developing, fixing, etc.; but after drying the film assumes its original size, and no shrinkage occurs after several months' storage. The new film is developed, fixed, and washed in the same way as the celluloid film; the pictures are identical and may be colored in a similar way.

Manufacture of Swedish Filter-Paper. G. FORNSTEDT. (*Chem. News*, cvii, 269.)—Chemical filter-papers are generally made on hand moulds, while those used for technical purposes are manufactured on cylinder machines. The carefully-sorted rags, freed from metallic impurities, are boiled with caustic soda and are preferably bleached in chambers with gaseous chlorine after washing and breaking. The ash in the purified, bleached half-stuff ranges from 0.177 for colored cotton rags down to 0.039 per cent. for new shirt cuttings. The water used must be very pure, but even then it generally introduces 0.02 to 0.05 per cent. of mineral matter into the paper. The beating is regulated according to the rapidity of filtration and fineness of retention desired. For analytical work the paper is extracted with hydrofluoric and hydrochloric acids and washed until the washings do not show any opalescence with silver nitrate. It is then pressed and hung in open sheds, where it is frozen to increase its porosity. If dried before freezing, the desired effect cannot be obtained. Extracted filter-paper contains about 0.015 per cent. of ash. Extreme precautions are taken for the determination of the ash in chemical filter-papers; the chief constituents are silica and calcium, aluminum, and magnesium oxides. The rate of filtration is determined on a paper 6 inches in diameter, through which 6 cubic inches of water at 90° F. (32° C.) should pass in 140 seconds as a maximum to 90 seconds as a minimum.

Liquid Fuel. V. B. LEWES. (*J. Roy Soc. Arts*, lxi, 666, 690, 702.)—This deals with the origin, composition, production, uses, and future supply of petroleum. The author considers that the greater quantity of petroleum has been formed by the slow decomposition of marine vegetation (sea-weeds, etc.). A table from A. Beeby Thompson's "Petroleum Mining" is given, showing the specific gravity and ultimate composition of the various kinds of petroleum,

whilst in another table the specific gravity, flash point, calorific value, and actual evaporative power of various kinds of liquid fuel are given; heavy tar oil is shown to be considerably inferior to a good petroleum fuel oil as a fuel. It is stated that air carburetted with petrol vapor gives good results in the Bone and McCourt system of flameless surface combustion, and experiments have also indicated that fuel oil, finely atomized with air in the correct proportion, and then blown into the tubes containing the granular material, will also prove efficient if the granular material be previously heated.

Stereophotographic Surveying. O. LEMBERGER. (*Eng. News*, lxix, 602).—A short history of the development of photographic surveying in Europe, with some examples of photographic location of certain railways, such as the Jungfrau Railway, and examples of topographical surveys. The theory of photogrammetry is briefly explained, and also the theory and practice of stereophotogrammetry. The instruments used for stereophotogrammetry, the stereomicrometer and the stereocomparator, are described, with diagrams of their construction and examples of their practical application. Finally, an instrument called the stereo-autograph is described, which automatically draws a map while an operator manipulates the stereocomparator. Contour lines may be drawn automatically on a map or on a photographic print. Illustrations are given of the use of the instrument for a survey of the Ostler Mountains in the Tyrol. Other possible uses are suggested.

Vulcanization of Rubber. G. BERNSTEIN. (*Z. Chem. Ind. Kol.*, xii, 193, 273.)—Experiments with different kinds of rubber showed that the viscosity is diminished by heating, by mechanical working, and by exposure to ultra-violet rays, and that if the depolymerization indicated by this reduced viscosity be carried to completion, the final result is the same, whatever the agency employed —*i.e.*, solutions of the depolymerized rubber of the same concentration show the same constant viscosity. With Frank and Marckwald's viscosimeter, and using a 3 per cent. solution of rubber in xylene, the final constant viscosity value is 15 seconds. Depolymerization on heating takes place most rapidly between 60° and 85° C., according to the kind of rubber, and these temperature limits are close to the temperature above which, according to Spence, vulcanization occurs most actively. The vulcanization of rubber can be produced by exposing a xylene solution of rubber and sulphur to ultra-violet rays. A xylene solution of a mixture of Hevea plantation rubber with 6 per cent. of sulphur was allowed to evaporate so as to leave a thin film on a transparent quartz plate. This was covered by another quartz plate and exposed on both sides for 40 minutes, at a distance of 15 cm. to the rays from a Heræus lamp of 3 ampères and 110 volts. The film then possessed

the properties of vulcanized rubber and contained 2.56 per cent. of combined sulphur. Other experiments showed that the percentage of combined sulphur increased with the duration of exposure to the rays. The deterioration of vulcanized rubber on exposure to ultra-violet rays, observed by Henri, is considered to be chiefly due to "after-vulcanization." The effect of heat or exposure to ultra-violet rays on sulphur alone or in solution is to polymerize it—*i.e.*, to convert it into a colloidal, insoluble form. Bernstein agrees with Axelrod that the vulcanization of rubber comprises a depolymerization of the rubber, followed by a polymerization of the mixture. If this polymerization of the mixture be of a physical character, it must be accepted that it is due to the adsorption by the depolymerized rubber of the polymerized insoluble sulphur, and this would explain the difficulty of extracting the so-called combined sulphur. It is, however, not yet possible to decide finally between the chemical and physical (adsorption) theories of vulcanization.

Mercury Vapor Lamp. ANON. (*Amer. Mach.*, xxxviii, No. 23, 933.)—The mercury vapor lamp would be ideal were it not so deficient in red rays. It has been found that by operating the lamp at much higher temperatures in a quartz tube the emanation of red rays increases as compared with green and blue rays. But even under these conditions the light it gives does not possess enough red for ordinary commercial purposes. Efforts have been made to find a vapor which will give the desired spectrum. Dr. Wolfke has apparently attained this end by the use of cadmium in the lamp. The vapor of cadmium gives an excess of red light when the temperature of the lamp is raised, but this is corrected by adding a little mercury. It is stated that a lamp of 3800 candle-power uses 620 watts.

Alunite and Kelp as Potash Fertilizers. J. J. SKINNER and A. M. JACKSON. (*U. S. Dept. of Agric., Bureau of Soils*, Circ. No. 76.)—Raw alunite of 10 per cent. potassium oxide, and ignited alunite of 14.7 per cent. potassium oxide, and dry kelp containing 19.8 per cent. potassium oxide, were added to the soil so as to give 25 to 500 pounds of potash per acre, and were compared with potassium chloride and sulphate. The raw alunite was not so effective as the potassium salts, but the ignited alunite was more effective, the average increase in the crop being about 31 per cent., as compared with about 25 per cent. for potassium sulphate. The kelp gave an increase of about 23 per cent. of the crop, as compared with about 22 per cent. with potassium chloride.

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